EFFECT OF CLIMATE CHANGE ON FARMERS' CHOICE OF CROPS: AN ECONOMETRIC ANALYSIS

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Saskatoon

By

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ABSTRACT

Climate change is being observed through increased average temperatures world-wide, as well as through increased frequency of extreme events, such as floods and droughts. As climate is an uncontrollable yet essential input in the agriculture industry, the impact of climate change may have on crop production in Saskatchewan is of importance. The main objective of this study is to investigate how farmers adapt to climate change by switching their crop mix, and how this crop mix may change under future climate change scenarios. A fractional multinomial logit (FMNL) model was used to assess how total area of cropland has changed over a thirty year time period. The panel data included variables to represent the land characteristics of Saskatchewan (i.e. the three major soil zones - Black, Dark Brown and Brown), climatic variables to represent average monthly temperature and precipitation, and price and policy variables in order to assess how average seeded area of each crop group changed. With these results, a simple simulation model was developed to evaluate how the area of each crop group in a base year comparison (2000) would change under future climate scenarios for each soil zone.

The results from the FMNL model indicate that crop allocation depends largely on the price of other crop groups and temperatures in the spring (April) and summer (July). Climate plays and important role in the major crop groups, such as wheat, canola and pulses. Cool, dry springs are the ideal conditions when choosing nearly all crops, while hot, wet summers increase the choice to leave land to summerfallow. Policy and the different soil zones also play a significant role in area allocation decisions. Changes in policies such as the removal of the Crow's Nest Pass Agreement, and the removal of oats from the Canadian Wheat Board (CWB) marketing, had a negative impact on the choice to grow wheat, as expected. The different soil zones in Saskatchewan played an important role in area allocation for a majority of the crops, having a negative effect on the choice of wheat over every other crop group except pulses and summerfallow.

Three climate change scenarios were simulated for each soil zone and compared to a base area (year 2000 area seeded) of crop groups. The findings from the projected changes in climate indicate that the area allocated to wheat will continue to decrease into the future, following current trends. The average projected decline in wheat area from the base years by 2099 ranges between 3.5% to 4.6% in the Black soil zone, between 2.7% and 2.9% in the Dark Brown and 2.7% to 4% in the brown soil zone, depending on climate change scenario. Interestingly, the area left to summerfallow is projected to increase over the future climate change scenarios. The choice of wheat is preferred over pulses, feed and forages, while the choice of specialty oilseeds (flaxseed, mustard seed and canary seed) are projected to become preferred over wheat in the future.

The major conclusion from this research are: (i) following current trends, the area devoted to spring wheat and durum wheat would continue to decline into the future; (ii) Area devoted to wheat remains a preferred choice over pulses, feed and forages while specialty oilseeds represent a viable alternative choice to wheat and (iii) most significantly, summerfallow area would increase. This is in contrast to the current trend of declining summerfallow area as a result of tighter crop rotations. This finding was observed throughout all three soil zones as well as for all three climate change projection periods. This will have major implications on individual farmers as well as the economy in Saskatchewan, as summerfallow does not produce a crop in the year it is chosen. It is therefore important to determine a possible new crop mix that would benefit from the projected change in climate. This study could be improved by including a measure of profitability for each crop group and introducing a new crop group that is better suited to the projected change in climate in Saskatchewan.

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CHAPTER 1

INTRODUCTION

1.1 Background

Climate change is evident from changes in average conditions as well as changes in climate variation and extreme events (Lemmen et al., 2008). The Intergovernmental Panel on Climate Change (IPCC, 2007) has concluded that climate change is being observed all around the globe with increased surface temperatures, shrinking mountain glaciers and snow cover in both the northern and southern hemispheres, rising sea levels and increased precipitation. Experts believe global warming[1] is caused by the accumulation of greenhouse gases[2] in the Earth's atmosphere (Shortle et al., 2009; Parry et al., 2009). There are also strong findings that if emissions are not curbed, the continued accumulation in the atmosphere will lead to a permanent change in climate (Weber & Hauer, 2003). A majority of climate change research predicts a higher level of warming for the northern latitudes resulting in a longer and warmer growing season; however there are predictions of drying and increased evapotranspiration projected for midcontinent regions (Sauchyn & Kulshreshtha, 2007).

Due to the threat of climate change on the general economy and society in general, many studies have been undertaken to examine its possible impacts on various economic sectors. Because weather is an important factor in crop production, agriculture is inherently sensitive to climate change. Being a major primary industry in Saskatchewan, an understanding of the impacts of climate change on agriculture is important. Among many factors, these changes may include: higher temperatures increasing crop yields through increased growing season length, increased precipitation partially offset by higher evapotranspiration, and increased frequency of extreme events, which may impart an adverse impact on the industry.

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[1] Global warming is one of the contributors to climate change. Although warming has been experienced on the planet in the past, the current trend in increased temperatures has increased at the fastest rate in recorded history (Natural Resources Defense Council, 2011).

[2] These gases include carbon dioxide, methane and nitrous oxide, plus a few other trace gases.

Currently, agriculture in Saskatchewan is challenged by a relatively short growing season (as a result of early frost) as well as from low and unreliable precipitation. If under climate change the growing season would be longer, there could be beneficial impacts on crop and livestock production. However, not all agricultural sectors will benefit by the same magnitude[3]. A general consensus is that the agriculture sector in Saskatchewan will have both positive and negative impacts as a result of climate change and these impacts would vary regionally (Lemmen & Warren, 2004).

Although climate change may impart potential changes, the net impact on crop production will depend on the adaption measures that are undertaken by producers. Altering production practices is included among these sets of measures, which can be accomplished at the farm level by methods such as irrigation, early seeding and crop diversification (Bradshaw et al., 2004; Bryant et al., 2000). The latter may involve changing the crop mix in order to adapt to a changing climate. Past studies have suggested that farmers do select their crop choice taking climate into consideration (MNS, 1994). These crop choice decisions could therefore provide an important adaptation strategy to a changing climate.

1.2 Problem Statement

Previous studies that have investigated how farmers' make cropping decisions used portfolio analysis (Lewandrowski and Brazee, 1993), ecological economic modelling (Fisher et al., 2005) and crop growth models (Easterling et al., 1993). In the early nineties, Mendelsohn, Nordhaus and Shaw [MNS] (1994, 1996) used the Ricardian approach to show how farmers were adapting implicitly to a changing climate. This method was applied for Canada by Reinsborough (2003) and Weber and Hauer (2003). In these studies the Prairie Provinces were treated as one homogenous area, when in reality this is far from accurate. Amiraslany (2010) used the Ricardian method to assess climate change impacts across the three Prairie Provinces, further disaggregating Canada and the Prairie Provinces.

[3] Some crops are more sensitive to heat stress and may not benefit from increased temperatures.

A more recent approach to modelling crop choice in response to climate change has used discrete choice models. The advantage over the Ricardian model is the explicit interpretation of crop choice. These studies have focused primarily on developing regions, for example, South America (Seo & Mendelsohn, 2009) and Africa (Kurukulasuriya & Mendelsohn, 2008). To date, this method of quantifying adaptation to climate change has not been applied in the context of Canadian agriculture.

Although Saskatchewan is a leader in agriculture production, it has some of the most diverse farmland, such as Palliser's triangle, which is characterized by aridity and an annual water deficit (Dale-Burnett, 2006), and transition zones between agriculture and forests in the north. Because weather is one of the most important determinants of agriculture production, farmers must adopt management practices that are dictated by weather patterns. Given the above noted impacts of climate change, one could conclude that there could be serious implications for the sustainability of agriculture. Some adaptation would become necessary under these conditions. In order to take advantage of opportunities due to predicted longer and warmer growing seasons, crop mix on farms may change. These changes would have major impacts on the welfare of crop producers, but may also have impacts on livestock producers, as well as the provincial and national economies. There is a paucity of studies in this area for Canada, as well as Saskatchewan. This study was developed to shed some light on changing crop mix as a strategy for adaptation to climate change for Saskatchewan producers.

1.3 Objectives and Scope of Study

The main objective of this study is to assess the role played by climate change and other economic and non-economic stimuli that influence crop mix choices by Saskatchewan producers. The information will be used to predict and assess future land use patterns as affected by future climate change and its implications.

This study is limited to the Province of Saskatchewan. As a result of the differing weather patterns and other biophysical conditions, spatial variability is evident. This variability in crop mix was considered explicitly by dividing the province into three soil zones.

1.4 Organization of Study

The remaining chapters of this study are organized as follows: chapters two and three provide an overview of agriculture in Saskatchewan and a literature review pertaining to the problem being addressed, respectively. Chapter four discusses the conceptual model and the theory of the fractional multinomial logit model and chapter five describes the empirical model that will be used in estimation. Chapter six reports the results and analysis of the study. Chapter seven presents the conclusions of the study including limitations and suggestions for further research.

CHAPTER 2

AGRICULTURE IN SASKATCHEWAN

2.1 Introduction

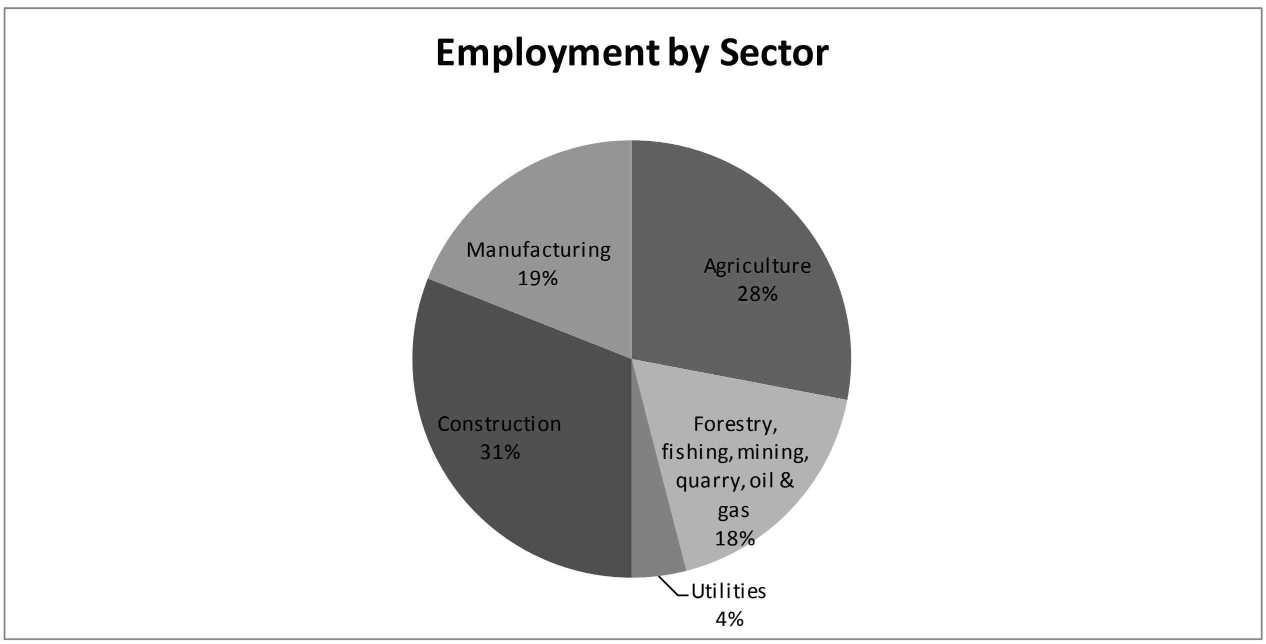
The provinces of Alberta, Saskatchewan and Manitoba combined are called the Prairie Provinces of Canada. Together they account for about 81% of the agricultural land in Canada, which contributes approximately 44% of the agricultural GDP in Canada (McCrae & Smith, 2000). Dominant production sectors are the livestock and field-crops (oilseed, grain and pulse production). Although Saskatchewan contributes to both of these agriculture sectors, crop production is relatively more dominant. Cropping patterns have changed overtime, from being primarily wheat production to various types of cereals, oilseeds and pulses.

This chapter focuses on a review of Saskatchewan agriculture, particularly on crop production. The chapter begins with an introduction of basic farm characteristics in section 2.2, which is followed by an assessment of its contribution in section 2.3. Climate of Saskatchewan is reviewed in section 2.4 followed by details of crop production reported in section 2.5 and livestock production in section 2.6. A brief conclusion of the chapter is presented in section 2.7.

2.2 Contribution of Saskatchewan Agriculture to Provincial Economy

2.2.1 Employment in the Agriculture and Agri-Food Sector

The agriculture sector of Saskatchewan is a 'goods producing sector' as described under the North American Industry Classification System (NAICS). In Saskatchewan there are many sub categories of this sector including agriculture; fishing, forestry and mining; construction and manufacturing. The agriculture sector is made up of both crop and animal production. Figure 2.1 details employment by goods producing sectors in Saskatchewan. These numbers represent only the employment of producers; however, there is a much larger facet to the agriculture industry in Saskatchewan. The agriculture and agri-food sector encompasses several more industries including the farm input and service supplier industries, food and beverage processing, food distribution, retail, wholesale and foodservice industries (AAFC, 2013). In Saskatchewan it was estimated that the average employment during 1998 to 2002 in agriculture production, food processing and agriculture inputs was about 65, 000 individuals, amounting to about 11.5% of total provincial employment (Kulshreshtha & Thompson, 2005). In 2012, this sector employed 40 thousand workers in Saskatchewan making agriculture the second most prominent goods producing sector in the province in terms of employment (Statistics Canada, 2013b) Taking into account these sectors, agriculture and its various related sectors contribute significantly to employment federally and provincially. Together, these sectors also play a critical role in exports and sales as one does not contribute without the other.

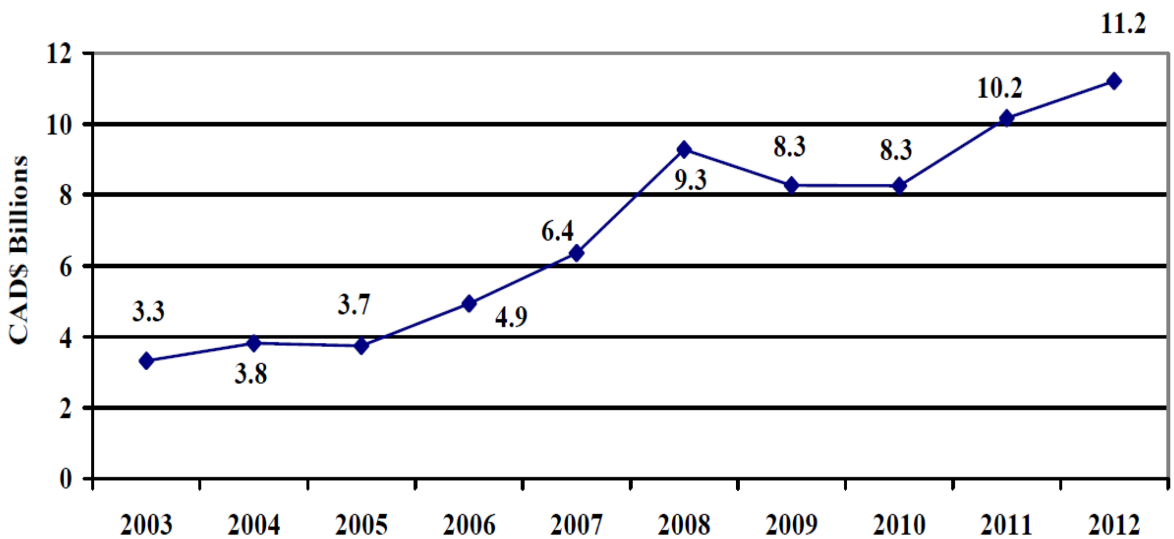


Source: Statistics Canada (2013b)

Figure 2.1: Distribution of Employed People by Industry in Goods Producing Sector, Saskatchewan, 2012

2.2.2 Exports of Agriculture Products

Saskatchewan exports contribute greatly to total gross domestic product (GDP), accounting for 70 percent of total provincial GDP (AAFC, 2011), with agriculture and agri-food products making up about one third (AAFC, 2012). Exports of agriculture products have steadily grown in Saskatchewan, accounting for $2.5 billion in 1990 and increasing to $3.4 billion in 2005 (Marshall, 2006). By 2010, agriculture exports were valued at over $8 billion (AAFC, 2012). In 2012, agriculture exports were the highest in Saskatchewan history at $11.2 billion (Norgate, 2013). Figure 2.2 shows the trend in agri-food exports from Saskatchewan to the rest of the world. A majority of these exports are comprised of three key commodity groups: cereal grains (wheat, durum, oats and barley), oilseeds (canola and flax) and pulses (peas and lentils) (AAFC, 2012).



Source: Norgate (2013)

Figure 2.2 Saskatchewan Agri-Food Exports to the World, 2003-2012

The US continues to be a critical trading partner with the province, importing 28 percent of all of Saskatchewan agri-food exports (Norgate, 2013). China is also an important trading partner importing 18 percent of total agri-food exports out of Saskatchewan, up from 5 percent in 2007 (Norgate, 2013).

The majority of these agri-food exports are grains such as oats and wheat as well as canola. India is a major importer of pulses and canola in recent years, while emerging markets such as Pakistan, Bangladesh, Sri Lanka and the Middle East and North Africa (MENA) have the potential to be important trading partners as their populations continue to grow (Saskatchewan Trade and Export Partnership, 2011).

2.2 Salient Features of Saskatchewan Agriculture

2.3.1 Land and Soils

In terms of land area, Saskatchewan covers 6.5% of total Canadian land area, an area of 651,036 square kilometres, of which 591,670 square kilometres are land and 59,366 square kilometres are covered by water (Saskatchewan Ministry of Agriculture, 2013b). The agriculture producing region occupies the Southern third of the province and accounts for 44% of the agriculture land in Canada (Saskatchewan Ministry of Agriculture, 2012b). The Northern third of the province is dominated by the Canadian Shield, which is characterized by a very thin layer of soil lying over bedrock composed of granite and Precambrian rock (Canadian Shield Foundation, 2013) and is generally not suitable for agriculture. This area is also largely dominated by tree cover and lakes. There are five different soil zones that are present in Saskatchewan – brown, dark brown, black, dark grey and grey. The brown, dark brown, black and some of the dark grey soil zones have deeper soils and therefore are the major crop production regions in Saskatchewan. Figure 2.3 shows the province of Saskatchewan's major soil zones.

2.3.2 Farm Characteristics

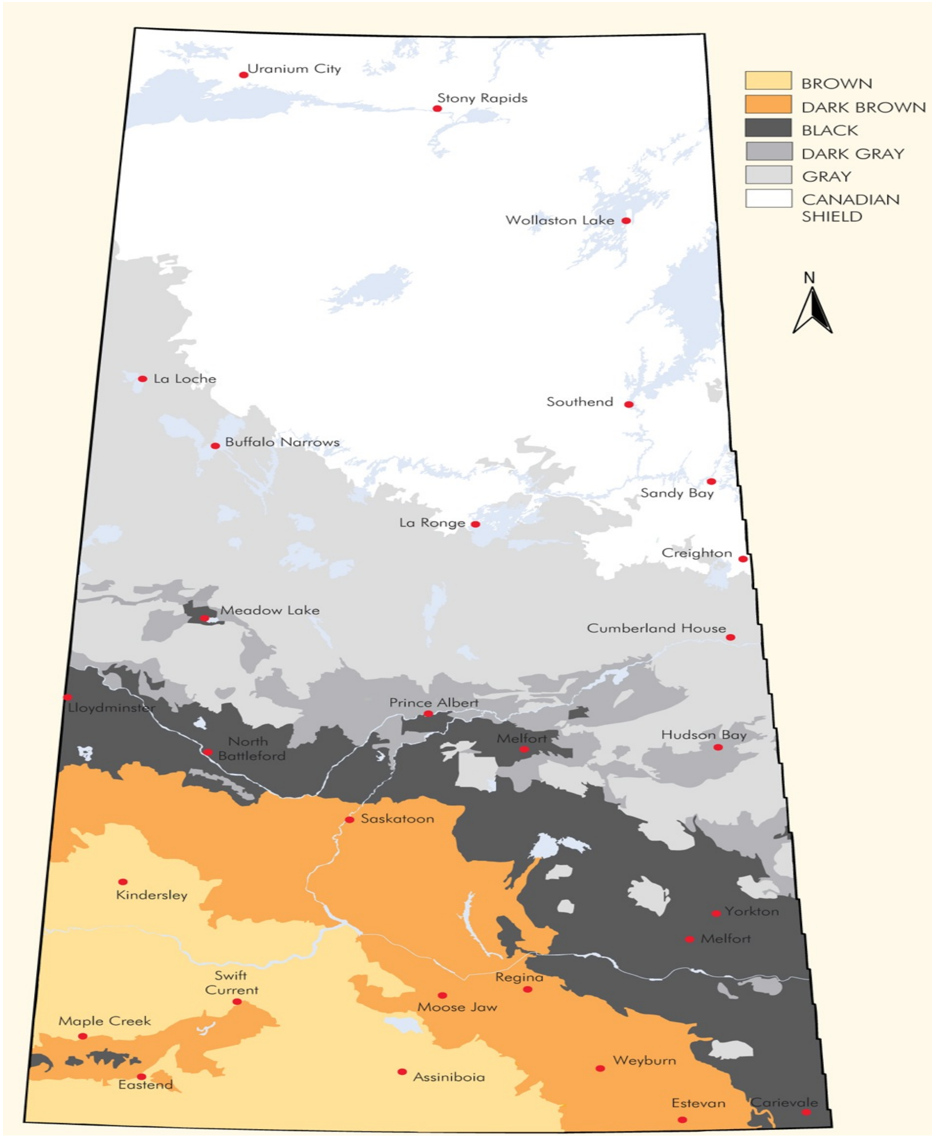
Farming has changed substantially over the years, which can be attributed to a number of factors, such as increased knowledge of improved agriculture production techniques by producers, environmental degradation caused by agriculture production, risks associated with farming and increased emphasis on research and development, among others. Although the area of land used for agriculture has changed only minimally through the years, farm size and crop production has increased significantly. Table 2.1 illustrates the trend in number of farms and average acres per farm.

At the core of agriculture production in Saskatchewan is the producer. One of the most significant changes in the past fifty years concerns the characteristics of the farm and farm operators. Between the years 1981 and 2011, the total number of farms in Saskatchewan decreased by nearly half, while the average farm size has increased just over 75 percent. According to Statistics Canada (2013a), in 2011 there were 36,952 farms in the province with an average size of 1,668 acres.

Table 2.1: Number and Area of Farms, Saskatchewan, 1981-2011

Year	**# of Farms**	**Total farmland (million acres)**	**Average size (acres)**
1981	67,318	64	952
1986	64,431	66	1,036
1991	60,840	66	1,091
1996	56,995	66	1,152
2001	50,590	65	1,283
2006	44,329	64	1,450
2011	36,952	62	1,668

Source: Statistics Canada (2013a)

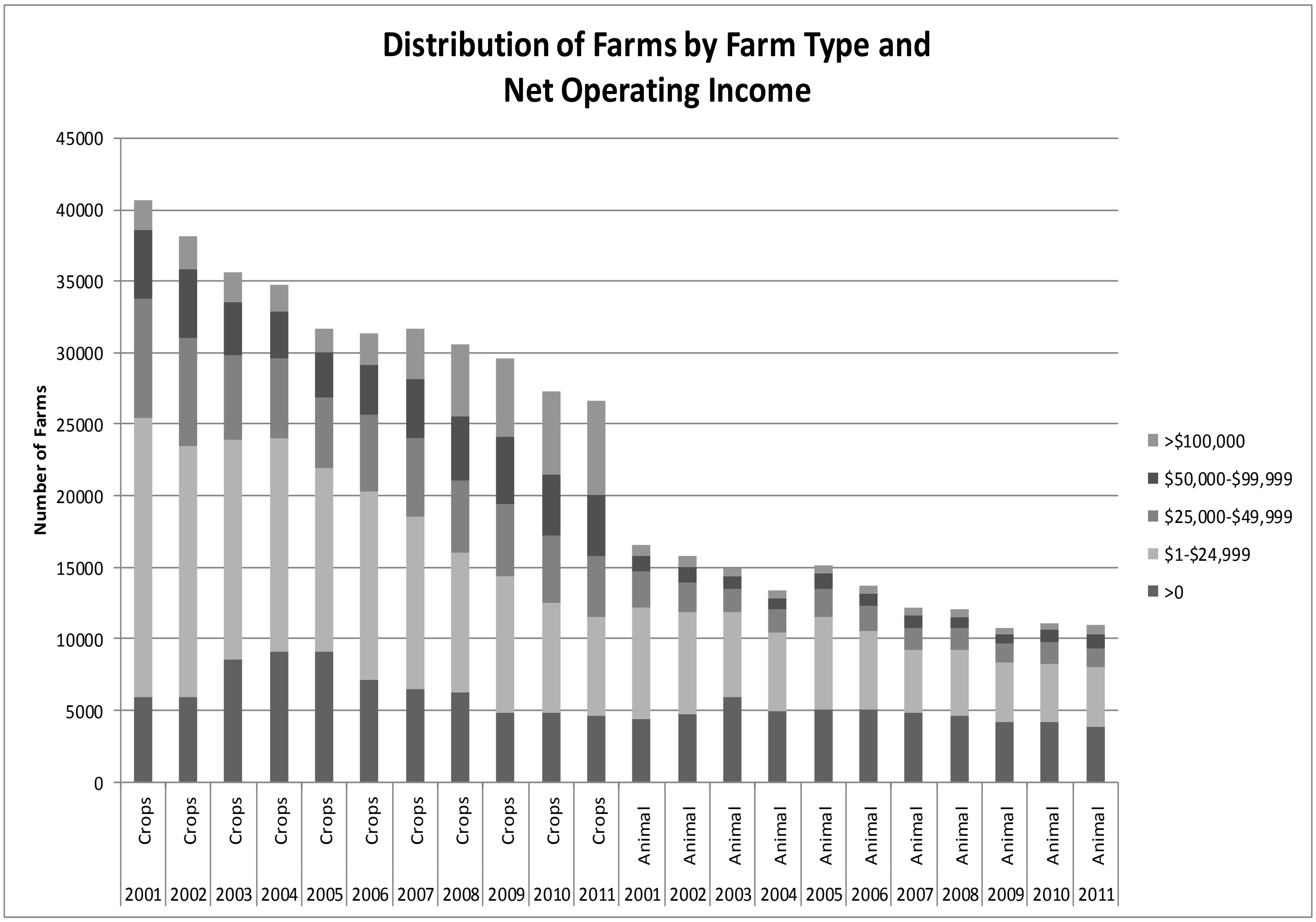


Source: Encyclopaedia of Saskatchewan (2006)

Figure 2.3: Map of the Province of Saskatchewan with Soil Zones

2.3.2 Sources of Income: Crop versus Livestock

The operating arrangement of farms has also changed, most notably, the number of unincorporated, individual or family farms have steadily decreased (about 50 percent in the past 30 years), while family farm corporations have increased by 40 percent since 1981. Another change that has been observed over the past ten years is the change in net operating income of farms. As the number of farms decreased, the average net operating income of farms producing crops has increased. More crop farms are generating a net operating income over $100,000 compared to just ten years ago. However, crop production has dwarfed animal production net income in Saskatchewan. Although both have been on the decline, a majority of livestock farms net operating income remains below $25 thousand per annum. Figure 2.4 illustrates these changes in more detail.



Source: Statistics Canada (2013e)

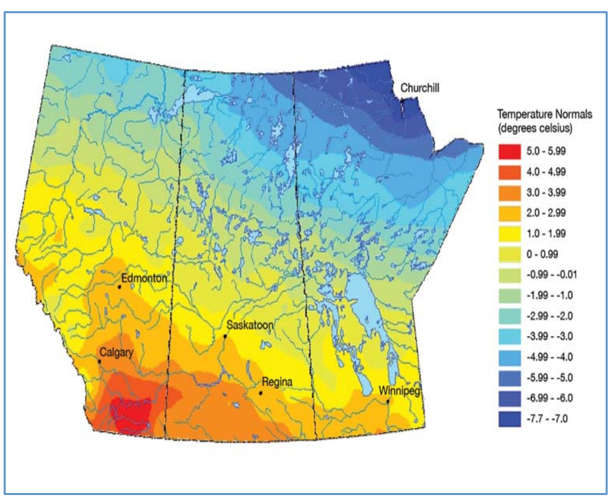
Figure 2.4: Distribution of farms, by farm type and net operating income[4] group, Saskatchewan, 2001-2011

[4] Total net income measures the financial flows and stock changes of farm businesses (net cash income minus depreciation plus income-in-kind and value of inventory change). It represents the return to owner's equity, unpaid labour, management and risk and it also used interchangeably with net farm income (Statistics Canada, 2012).

2.4 Climate of Saskatchewan

Because Saskatchewan covers a large area, it has diverse weather patterns. Figure 2.5 shows the different extremes in temperature and precipitation that occur across the Prairies Provinces. The southern parts of the province experience the warmest winter and summer months (-10 degrees Celsius and 16 degrees Celsius, on average, respectively) of the entire province as well as the least amount of annual precipitation (250-350 mm) (University of Saskatchewan, n.d.a). High temperatures exacerbate the moisture deficits experienced in this region by increasing evapotranspiration. The area through the middle of the agricultural producing region of the province has lower temperatures (-11 degrees Celsius in the winter and 15.5 degrees Celsius in the summer, on average) and slightly more annual precipitation (350-400 mm) (University of Saskatchewan, n.d.a). The area north of Saskatoon experiences similar temperature as the central area (-12 degrees Celsius in the winter and 15 degrees Celsius in the summer) but has the highest annual precipitation (400-500 mm) (University of Saskatchewan, n.d.a).

a)



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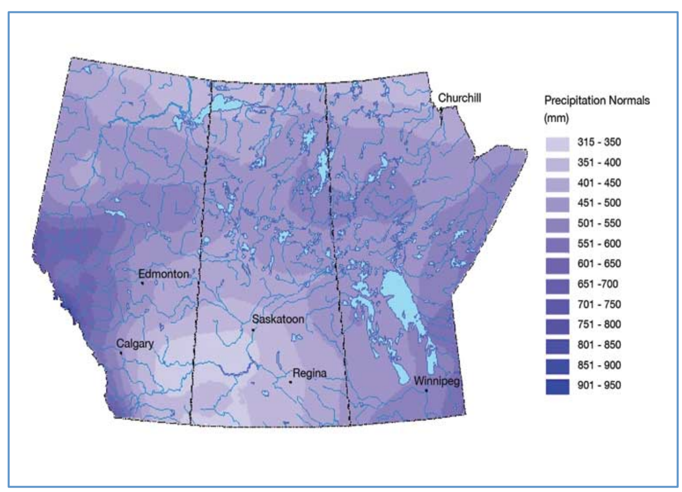


Source: Sauchyn and Kulshreshtha (2008)

Figure 2.5: Climate Normals (1961-1990) for the Prairies (a) temperature and b) precipitation

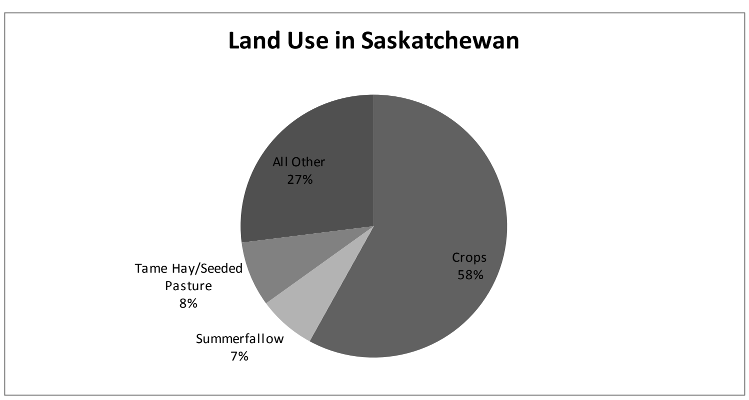
2.5 Crop Production in Saskatchewan

Saskatchewan accounts for 41 percent of Canada's arable land, estimated at approximately 65 million acres (26.3 million ha). Of this area, approximately 33 to 37 million acres are used for crop production each year. Figure 2.6 illustrates the percent of land devoted to crop, summerfallow, seeded pasture and other uses in 2011. Table 2.2 shows the historical changes in crops, summerfallow and pasture in Saskatchewan by census year. The land devoted to crops has steadily increased over the past 30 years while summerfallow has decreased substantially as zero tillage technology has developed and tighter crop rotations have become more common. Pastureland has also increased due to increased livestock production in the province; however this increase is far less than that observed by area devoted to crop production.

Table 2.2: Farmland Area by Land Use, Saskatchewan, 1981-2011

Total Area of Farmland & Use of land (million acres)	*1981*	*1986*	*1991*	*1996*	*2001*	*2006*	*2011*
Land in Crops	29	33	33	36	38	37	36
Land in Summerfallow	17	14	14	11	8	6	4
Tame/Seeded Pasture	2	2	3	3	3	5	5

Source: Statistics Canada (2013a)

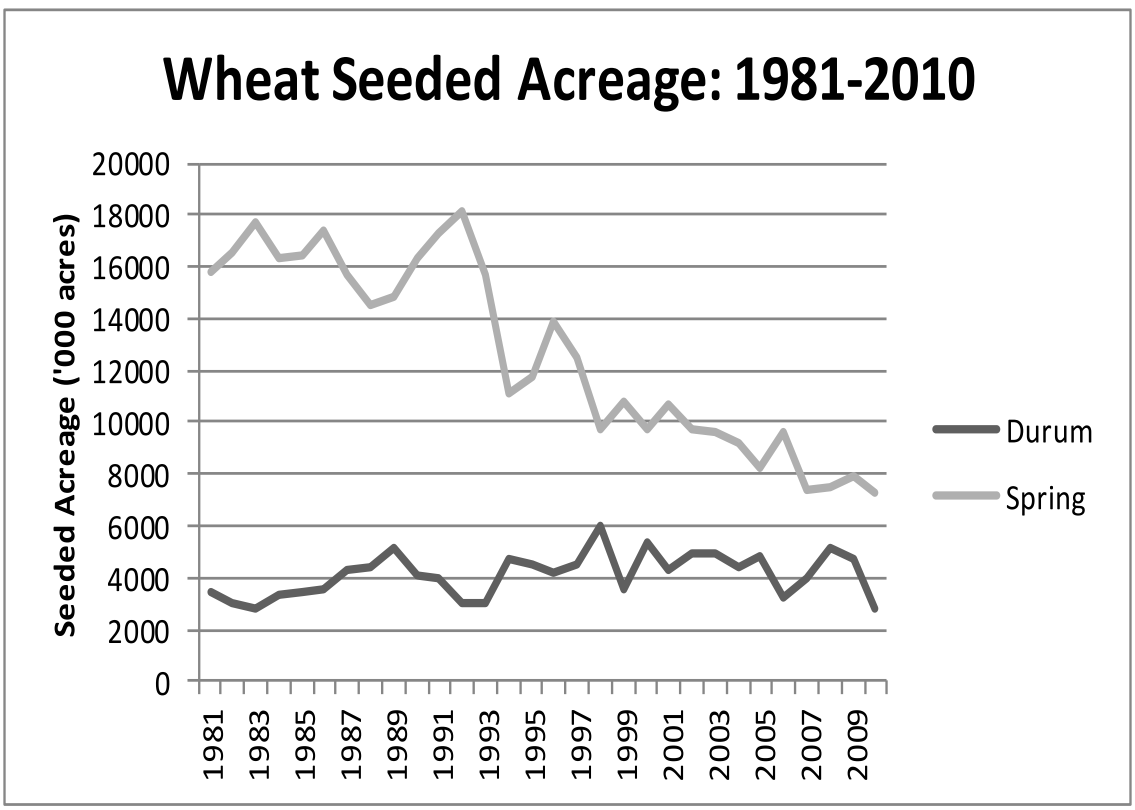


Source: Statistics Canada (2013a)
Figure 2.6: Land Use in Saskatchewan, 2011[5]

[5] Other land uses include Christmas trees, wetland and woodlands, and land too wet to seed.

2.5.1 Wheat

In the late 1800s, with a push from Prime Minister John A. McDonald, the prairies were settled and a railroad was built to transport the agriculture production across the country (Bitner, 2010). By the early 1900's much of the West was settled and crop production was the primary industry with wheat being the principal crop grown. Although the early varieties of wheat were not well suited for the short growing season in the province, other varieties were developed at the numerous plant breeding centers across Canada (Symko, 1999). More hardy varieties, better suited for the climate of the prairies, were developed through the years and wheat became a staple crop synonymous with the prairies. Figure 2.7 depicts the change in seeded area between the years 1981 to 2010 of the two primary wheat types grown in the Prairies: spring wheat and durum wheat.



Source: Saskatchewan Ministry of Agriculture (2013a)

Figure 2.7: Wheat Seeded Acreage in Saskatchewan, 1981-2010

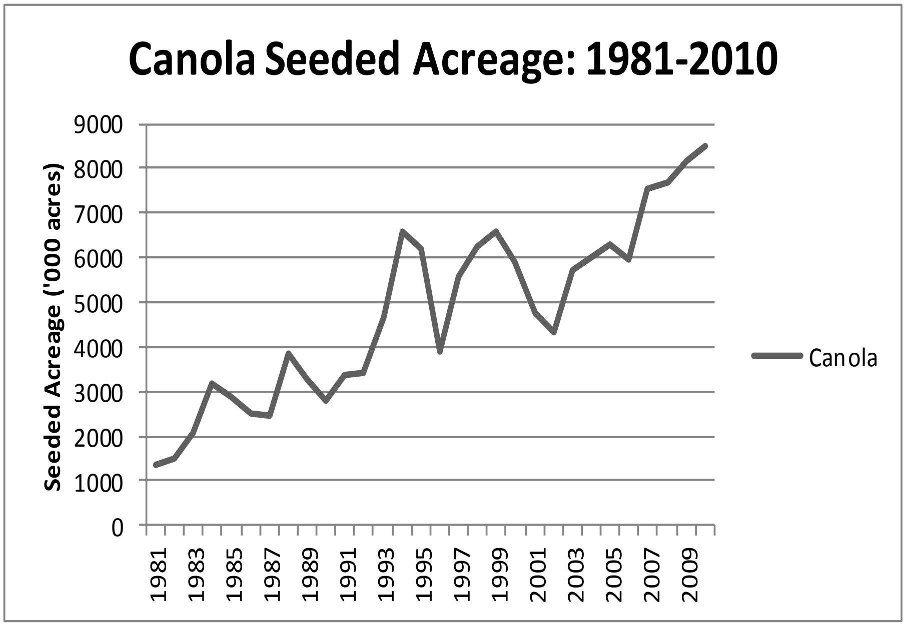
Figure 2.7 shows that the seeded acreage of durum wheat has remained relatively constant through the time period. There is only one marketed durum wheat variety (Canada Western Amber Durum) in Canada and about 85% of Canadian durum wheat is grown in Saskatchewan (Saskatchewan Ministry of Agriculture, 2012d). It is also primarily grown in the portions of the province that experience lower rainfall, such as in the dark brown and brown soil zones (Hucl, 2006). In contrast, spring wheat has multiple varieties that are produced in the Prairies with the major differences being the protein content and the yield of each variety. The area of spring wheat has been steadily decreasing over the last two decades as new crops have been introduced into the crop rotation in response to price and other factors.

2.5.2 Oilseeds

Another important crop to Saskatchewan was developed in the 1970s called canola (Raymer, 2002). Canola was developed from rapeseed to improve the nutritional quality of the meal and oil after the health concerns over erucic acid, which was present in rapeseed, were identified (Raymer, 2002). Due to increased research and development by both the public and private sectors, canola became a significant crop on the prairies. In Saskatchewan alone, production of canola increased drastically over the years, accounting for just over one million seeded acres in the early 1970's to over seven million in recent years (Saskatchewan Ministry of Agriculture, 2013a). The trend in production (approximated by seeded acreage[6]) is shown in Figure 2.8. It was also one of the few crops produced that was not sold through the Canadian Wheat Board (CWB). Canola production was marketed through the 'open'market.

[6] Farmers decisions can be approximated by seeded area as this is the initial land allocation of crop choice made by farmers in the current crop year.

Canola became the first 'cash crop' on the prairies and a viable option to include in the crop rotation to combat disease and pests present in the soils.[7]



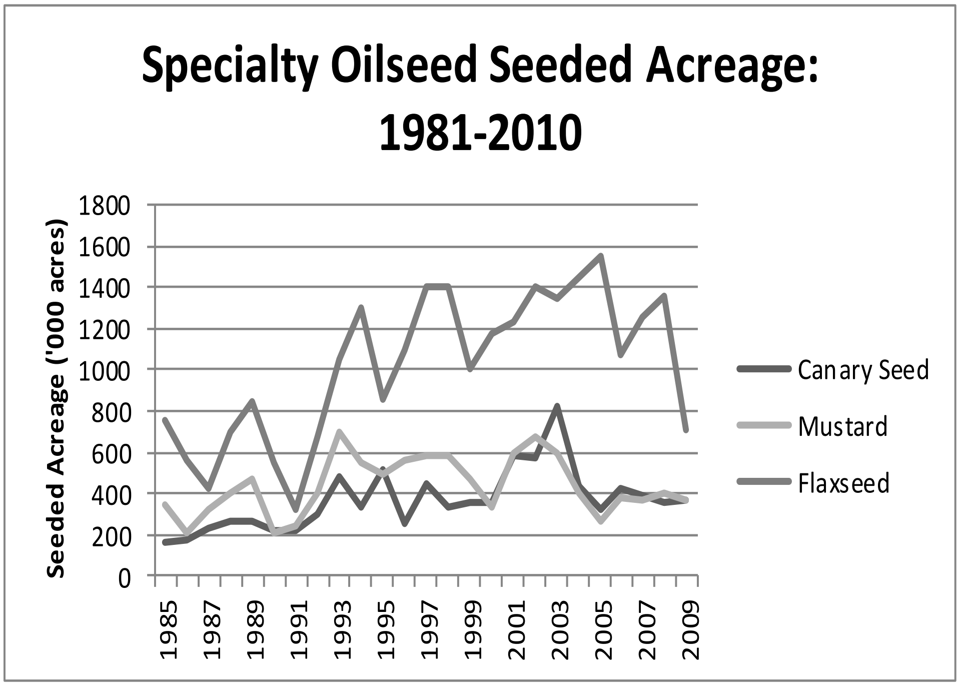
Source: Saskatchewan Ministry of Agriculture (2013a)

Figure 2.8: Canola Seeded Acreage in Saskatchewan, 1981-2010

In addition to canola, there are three other oilseeds grown in Saskatchewan – mustard seed, flaxseed and canary seed. Mustard seed has been grown for many years in Saskatchewan and Alberta with Canada being the world's largest exporter (Greuel, 2006). Canary seed is primarily grown in Saskatchewan and Manitoba and is another crop for which Canada is the top exporter (Saskatchewan Ministry of Agriculture, 2012a). The final oilseed, flaxseed also puts Canada at the top, making it the largest producer and exporter of flaxseed in the world. In fact, Saskatchewan grows four times more flax than any other Canadian province (Saskatchewan Flax Development Commission, n.d.). Flaxseed is seeded more than both mustard seed and canary seed in Saskatchewan and was steadily increasing until genetically modified seed was found in a shipment to the European Union (Canadian Biotechnology

[7] Continuous cropping of similar crops has many disadvantages including decreased yields, soil degradation, increased disease and insect infestations (Bullock, 1992). It has been long suggested that sustainable agriculture involves rotations between crops of at least three to four years (Bayer CropScience, n.d).

Action Network, n.d.). Given EU's low tolerance for GMO products, this shut down Canadian trade to the EU for flaxseed temporarily, and has resulted in lower area devoted to this crop in the years following 2007. Trend in seeded area for the three oilseeds are shown in Figure 2.9.

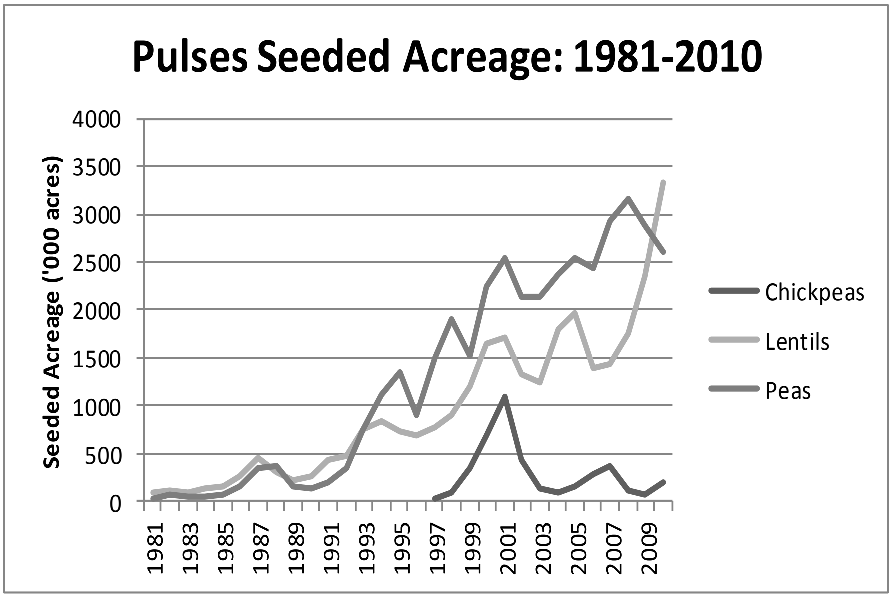


Source: Saskatchewan Ministry of Agriculture (2013a)

Figure 2.9: Specialty Oilseed Seeded Acreage in Saskatchewan, 1985-2010

2.5.3 Pulses

In the late 1980's, legumes, more commonly known as pulses, were introduced to Saskatchewan. These crops included peas, lentils and chickpeas. During the earlier phase of their introduction, dry peas were the most common pulse crop grown. This change was also supported by the fact that dry peas added substantially to the crop rotation. Seeding a pulse crop increased the length of the crop rotation, thereby decreasing the damaging effects of continuous cropping cereals and oilseeds. Growing pulses was also greatly beneficial to the soil due to the nitrogen fixing capability of the roots; the result is an increase in the nitrogen content of the soil and less need for fertilizer application the following year (Saskatchewan Ministry of Agriculture, 2007). Other pulses, such as lentils and chickpeas, have become popular in Saskatchewan in more recent years with area of all three crops representing over six million seeded acres by 2010 (Saskatchewan Ministry of Agriculture, 2013a). A trend in their area is shown in Figure 2.10. Pulse crops constitute another example of a 'cash crop' for Saskatchewan farmers, since they are not under the control of the CWB. In addition, most of this production is destined for exports, where market prices have been more favourable in recent years.



Source: Saskatchewan Ministry of Agriculture (2013a)

Figure 2.10: Pulses Seeded Acreage in Saskatchewan, 1981-2010

It is important to note that although peas and lentils were present though the 1980's, their area accounted for a very small proportion of the total seeded area in the province. During that period, data on these crops were not well documented because of their small area relative to the larger area crops, such as canola and wheat. One reason for this smaller area was the agronomic suitability of these crops in various regions of Saskatchewan. For example, dry peas need high moisture content in the soils during seeding as well as warmer soils which is difficult to achieve during Saskatchewan springs (Saskatchewan Ministry of Agriculture, n.d.). All three pulse crops are considered cool climate crops that can withstand some drought as well high temperatures. At present production occurs in the brown and dark brown soil zones with some production of lentils in the black soil zone in years without excessive moisture (McVicar et al., 2010). Table 2.3 shows the average regional distribution of peas and lentils by crop district. The production of both peas and lentils has increased dramatically in the past two decades as new varieties have been developed and trading opportunities have flourished.

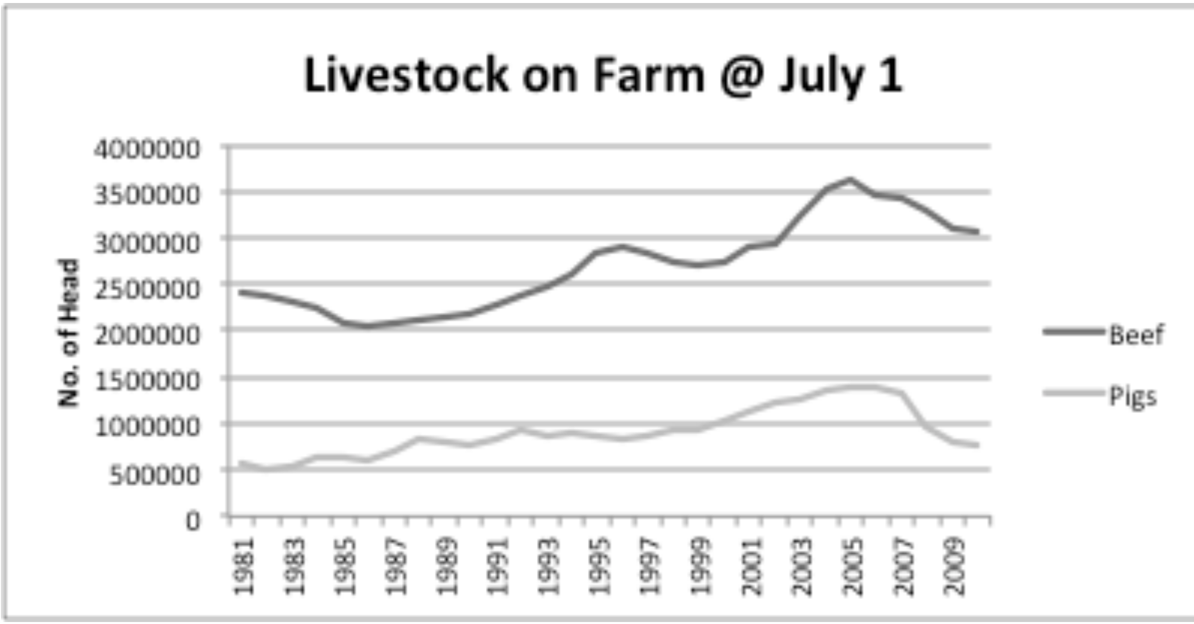
Table 2.3: Average Regional Distribution of Peas and Lentils by Crop District, Saskatchewan, 2001-2010

	5 year average (2006-2010)		**10 year average (2001-2010)**	
Crop District	***Peas***	***Lentils***	***Peas***	***Lentils***
1	153, 468	81, 176	158, 763	63, 158
2	548, 439	426, 035	241, 794	418, 979
3	844, 937	670, 665	681, 362	597, 146
4	158, 772	54, 081	124, 842	45, 795
5	195, 366	36, 133	271, 752	41, 309
6	412, 491	354, 812	367, 600	316, 640
7	297, 572	380, 970	255, 826	314, 740
8	161, 094	12, 539	209, 473	11, 355
9	300, 955	13, 742	304,634	10, 751

Source: Saskatchewan Ministry of Agriculture (2013a)

2.6 Livestock & Feed Production

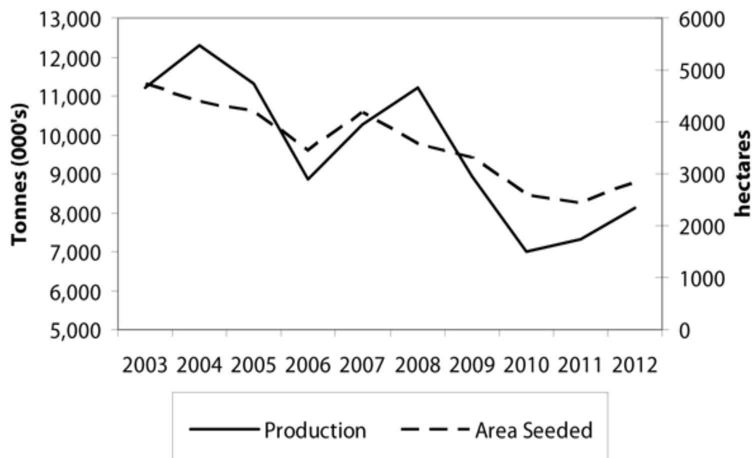
The second sector of Saskatchewan agriculture is livestock, comprised primarily of pigs and cattle but also sheep, elk and buffalo. Both the cattle and the hog industries have experienced various setbacks in the past few years. One of the major negative impacts on the cattle industry was the 2003 outbreak of bovine spongiform encephalopathy (BSE). This event closed the borders to virtually all of Canada's trading partners. The damage done by this event was estimated at $11 million per day in just two months (CBC News, 2006). It also affected an estimated 90, 000 producers in the three Prairie Provinces. The cattle industry took years to recover from this incident and many Saskatchewan farms suffered economic losses. Another negative impact over the past few years on both the beef and hog sector is through exchange rate fluctuations, accompanied by increased costs for feed and infrastructure (Informa Economics and Government of Saskatchewan, 2009). Figure 2.11 shows the change in cattle and pig inventory over the 1981 to 2010 period. Note that starting in 2003, on farm cattle inventory increased until reaching a peak in 2005 when some trading bans were lifted.



Source: Saskatchewan Ministry of Agriculture (2013a)

Figure 2.11: On-Farm Beef cattle and Pigs Inventory, July 1, Saskatchewan, 1981-2010

As mentioned above. one of the negative impacts on the livestock industry has been the rising costs of feed and infrastructure. Although there are different sectors within each livestock industry ranging from cow/calf operations to finishing operations, the majority of the negative impacts are felt by the cow/calf operations. However, an advantage that these producers have over a feedlot is that in some cases they are able to produce their own feed. Feed can be used from the production of forages as well as crops including oats, barley, rye and wheat. Rye, barley and wheat used to fall under the marketing jurisdiction of the CWB; however both spring and fall rye and winter wheat are usually grown and used as on-farm feed. These crops can also be sold locally but are often stored on farms for the purpose of feeding livestock. Barley can be grown for the malting industry or for the food and feed industry; however malting barley has strict acceptance criteria and therefore production requires much greater care and management (Saskatchewan Ministry of Agriculture, 2010). Therefore some seeded acreage of malting barley does not meet the requirements to be marketed as malting barley and must go to different markets such as food and feed (see Figure 2.12 below).



Source: Canadian Grains Commission (2012)
Note: production is on left axis, area seeded on right

Figure 2.12: Annual Production and Seeded Area to Malting Barley, Saskatchewan, 2003-2012

2.7 Agriculture Policy and Institutions in Saskatchewan and Canada

2.7.1 Policy

Over the years Saskatchewan has had many different agriculture policies that have been implemented to help producers and consumers of agriculture products. One area of policy that has impacted agriculture in Saskatchewan is transportation policies. The Crow's Nest Pass Agreement was inaugurated by the Government of Canada in 1897 as a subsidy to the Canadian Pacific Railway (CPR) company to lower the high transportation costs incurred by farmers in the prairies (Regeher & Norrie, 2013). Rail costs eventually escalated and the gap between the fixed Crow Rate and the rail costs incurred in moving grain increased, leaving the railway to pick up the slack (Harvey, 1982). In 1983 the Western Grain Transportation Act (WGTA) was passed and became effective in January of the following year. The new agreement allowed the railways to increase shipping costs gradually, but never exceed 10% of the world grain price while the remaining shipping costs were made up by the federal government (Regeher & Norrie, 2012).

Under the new WGTA, freight rates continued to be set by the government on a cost recovery basis, and a government-appointed board was given the responsibility of ensuring that future increases in rail costs were shared between the railways and Western grain producers (Doan & Dyer, n.d). However, production of grains was still favoured over other crops as transportation of these was highly subsidized until in 1995 the WGTA was repealed (Doan & Dyer, n.d). The current movement of grain to major ports involves prices set yearly by the railway companies; however this is capped by the federal government and any overages are paid out to farmers at the end of the year (Transport Canada, 1999). Because there are no direct subsidies on specific commodities, this allows diversification of crops without the looming cost of excessive transportation costs.

One of the major areas of agriculture policies implemented federally is to protect farmers as well as consumers from the volatile commodity markets. These policies or programs can generally be placed under an umbrella term of 'safety net programs'. These specific programs have a long history in Canada and continually undergo changes to improve efficiency and effectiveness. Examples of these programs include the WGSA (Western Grain Stabilization Act), ASA (Agriculture Stabilization Act), GRIP (Gross Insurance Revenue Program) and NISA (Net Income Stabilization Account). The latter two replaced the former two, but the main objectives of these programs were to pay out cash to farmers when market prices of commodities remained depressed (King & Narayanan, 1992). The goal was to keep farmers producing crops despite the economic difficulties in years of low commodity prices.

There are also some programs that are implemented to protect the land. One example of these programs is the Permanent Cover Program (PCP). The PCP program was implemented in the Prairie Provinces with the purpose of taking marginal land out of crop production to reduce soil degradation. Farmers that seeded marginal land to forage or tree cover for the next ten to 21 years received a price of $20/acre (Vaisey et al., 1996). The Prairies Farm Rehabilitation Administration (PFRA) delivered the program[8] and sign up was available for three years between 1989 and 1992.

2.7.2 Institutions

The major agriculture institution that has influenced grain production in Western Canada is the Canadian Wheat Board (CWB). The CWB was implemented in 1935 and was charged with the marketing of grains in the Western Canadian Provinces - Alberta, Saskatchewan and Manitoba and parts of British Columbia (Gilmour, 2006). The CWB was the single desk seller of grains in Western Canada and acted as a monopsony for Western Canadian grain producers. The grains marketed through the CWB included wheat, barley, oats and other feed grains (Veeman & Veeman, 2012). Participation by producers was optional in the early years of the CWB; however by 1943 marketing through the CWB of all grains was mandatory (Veeman & Veeman, 2012). In 1974, interprovincial movement of grain for feed was removed from the CWB marketing and in 1983 oats were completely removed from the jurisdiction of the CWB, leaving only wheat and barley on the board (Gilmour, 2006). In the summer of 2012 the CWB monopsony over wheat and barley officially ended, although farmers still have the option to market through the board (Canadian Wheat Board, 2013).

[8] The PFRA name has been changed several times. It was first changed to AESB – Agri-Environmental Services Bureau, and then to Science and Technology Branch of Agriculture and Agri-Food Canada.

2.8 Conclusion

Crop production is a key part of the Saskatchewan economy and has implications for the Canadian economy as well. Cereals, oilseeds and pulses are important contributors to crop rotation and soil conservation. From the early days of continuous cropping and degradation of soil and land, agriculture in Saskatchewan has become more diverse and efficient. It contributes to the economy of the province and due to the production of a variety of crops, has opened up new trading opportunities for Canada. From this review it is clear that agriculture in Saskatchewan is important for both the province and the country. The next chapter will give the literature review pertaining to the various methods used to study adaptation to climate change in agriculture, specifically crop production.

CHAPTER 3

LITERATURE REVIEW

3.1 Introduction

The goal of this chapter is to briefly review the literature pertaining to the impact of weather (and/or climate) on field crops and how these events influence crop production decisions. Section 3.2 is the literature review covering supply response, focusing on its application in Canada. Following that is a broad review of global climate change in section 3.3, followed by a review of various approaches used to measure impact of climate change in section 3.4. The strengths and weaknesses, as well as the appropriateness of these methods in the context of the research question are discussed in detail. The final section concludes with the choice of the applicable model used in the study to answer the proposed research question.

3.2 Supply Response Literature

Supply response literature is vast and many developments have taken place, including the use of methods such as optimization, simulation, linear programming and recursive programming, among others. In addition, studies have also incorporated the impact of public policies on producers' decisions related to the supply of a commodity. One of the most significant contributions in this area was made by Nerlove (1965), who introduced dynamics through farmers' price expectations into supply response models. His initial work developed equations to better understand how farmers' planned area of a given crop depended on past crop prices. Nerlove (1965) hypothesized that farmers react to expected prices. Most frequently this may depend, only slightly, on the previous year's price. His insight gave way to Nerlovian response functions that have been used for many years in supply response literature.

Skold and Westhoff (1988) extended the Nerlovian models to include policy effects. Many countries, including Canada and the United States, have policies to aid the agriculture industry, which is subject to volatile commodity prices (Nerlove, 1965). Participation rates in these programs were shown to influence acreage allocation decisions. As support for major crops, such as corn and soybeans, in the US wavered, so did the allocation decision of farmers (Skold & Westhoff, 1988). Lee and Helmberger (1985) also explored the impact of policy on acreage allocation decisions by modeling 'free market' and 'farm program' regimes in the Midwest US. They found that the supply elasticity of corn was greater than that of soybean under the different programs.

In Canada, supply response was studied in the early nineties by Meilke and Weersink (1990) and von Massow and Weersink (1993). The former study examined the effect of government stabilization programs on crop area allocation for both Eastern and Western Canada. Because of the extreme differences in the policy between these two regions, most notably the WGSA, there was a need to distinguish between these two regions. Expected prices, expected yields and policy variables were used as determinants of supply at the farm level. Using seemingly unrelated regressions (SUR) to estimate area allocation, followed by policy simulations, Meilke and Weersink (1990) found that area of high valued crops[9] in the West would decrease substantially with the removal of the WGSA. This result supported their hypotheses that farmers took into account prices as well relevant policies when making acreage allocation decisions.

Von Massow and Weersink (1993) conducted similar research but focused on specialty crops in Ontario. They hypothesized that support programs for high valued commodities, such as spring wheat and durum, would suppress production of specialty crops. Using a utility maximization situation that included price and yield uncertainty to represent risk, they hypothesized that acreage allocation

[9] High valued crops in this context were those that were subsidized by the WGSA such as rye, wheat and durum. These crops were favoured over other crops due to the subsidization.

depended on initial wealth, costs and the risk factors. Based on these assumptions, policy implications were simulated and it was found that most policies present in the East [such as Agriculture Stabilization Program (ASA) and Gross Revenue Insurance Program (GRIP)] do favour high valued crops; however there are some policies, such as National Tripartite Stabilization Program (NTSP), that benefit specialty crops. Von Massow and Weersink (1993) also pointed out that most of these policies change over the years, and there is a certain level of political pressure that exists when developing these programs.

From the above it is clear that supply response does depend on a few key factors. The current policy regime has a serious impact on the allocation decisions of farmers. Those policies that tend to favour certain crops and those that bias production decisions need to be accounted for. It is also important to include some economic measures when quantifying acreage allocation decisions -- the most important being expected prices and costs of production. One of the missing links in this area of research is that it does not include the impacts of climate and climate variability on farmers' cropping decisions. As one of the major, as well as uncontrollable, inputs in agriculture production, climate is an important determinate of acreage allocation decisions.

3.3 Climate Change

3.3.1 Global Climate Change

Climate change, as defined by the Intergovernmental Panel on Climate Change (IPCC)[10], is a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). Furthermore, IPCC has attributed this change in climate to natural internal processes or external forcings, or to persistent anthropogenic changes in the

[10] The IPCC is the leading research organization on climate change. It was established by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) in 1988 to provide the world with a clear scientific view on the current state of knowledge in climate change and its potential environmental and socio-economic impacts.

composition of the atmosphere or in land use. As mentioned in Chapter 1, climate change has been of major concern in recent decades, since its impact has been observed all over the world. There are various implications of changing climate and some of these implications have been studied (see Tol, 2009 and Mendelsohn et al., 2006). Development of climate change scenarios and impact assessments began in 1990 and still continues. The leading assessment of research on climate change has been undertaken by a group of scientists under the umbrella of the IPCC. They have released reports since 1995, with the last report released in 2007.

Using multiple climate change models, depending on the emissions scenario, the IPCC (2007) projected (with a greater degree of confidence than previous assessments) that overall world temperature would increase, on average, between 1.1 °C to 6.4 °C by the end of the 21st century. Table 3.1 describes the projected changes in climate under the different scenarios. However most of these predictions suggest increased temperatures and precipitation for most areas (Houghton et al., 2010). It is also predicted that precipitation will vary annually, resulting in an increase in extreme events such as drought and floods (IPCC, 2007).

3.3.2 Climate Change in Saskatchewan

Recently, Price et al. (2011) have conducted studies on climate change scenarios in Canada. Four well-established general circulation models (GCMs) forced by each of three greenhouse gas (GHG) emissions scenarios recommended by the IPCC were used to assess the impact (Price et al., 2011). Dividing Canada into different ecozones, this study was able to estimate climate change impacts on specific regions of Canada. Results suggest that impacts are not going to be uniform across Canada.

Table 3.1: Global Climate Change Scenarios and Projection of Temperature Change for 2009-2099

Case	Description	Temperature Change in °C at 2090-2099 relative to 1980-1990[11]
A1	Increased technological advance, rapid population and economic growth, more homogenous culture and society	1.4 - 6.4
A2	Economic development regionally oriented, technological change fragmented and slower by region, heterogeneous culture and society	2.0 - 5.4
B1	Increased service and information economy, decreased material intensive industry, introduction of clean and resource efficient technology, emphasis on global solutions to economic, social and environmental sustainability	1.1 - 2.9
B2	Emphasis on local solutions to economic, social and environmental sustainability, continually increasing global population, less rapid technological change	1.4 – 3.8

Source: Adapted from (IPCC, 2007)

In the Price et al. (2011) study, the prairies were divided into two zones: semiarid and subhumid. The latter ecozone is mostly tree cover in the more northern areas of the provinces. The results from the GCMs showed that out of all of the other ecozones, the semiarid area was expected to have the highest warming in the winter months by year 2100 (up to 5.5°C from current average conditions). Summers were also expected to warm by up to 4.5°C as well as an 8 and 15 percent increase from current average conditions in precipitation. Price et al. (2011) also pointed out that there will be inter-annual variations with precipitation, with multiyear droughts being more common in the future.

[11] Emissions are held constant at year 2000 levels for all climate change projections. Estimates are assessed from a hierarchy of models that encompass a simple climate model, several Earth Models of Intermediate Complexity (EMICs), and a large number of Atmosphere-Ocean Global Circulation Models (AOGCMs) (IPCC, 2007).

3.3.3 Impact on Agriculture

Because of the inherent vulnerability of agriculture to climate, several studies have been undertaken examining potential impacts of various climate scenarios on agriculture (see Darwin et al., 1995; Deschênes & Greenstone, 2007; Lobell & Field, 2007). As it has been mentioned above, these impacts are not going to be the same for every region across the prairies and the impacts may be positive or negative. Table 3.2 adapted from Lemmen et al. (2008) and Sauchyn and Kulshreshtha (2008), summarizes the potential impacts of climate change on agriculture, specifically crop production, in Canada.

Table 3.2: Positive and Negative Impacts of Climate Change on Agriculture, Prairie Provinces

Change in Climate	Impact on Agriculture	
	Positive	Negative
• **Increased precipitation** • **Increased temperatures** • **Increased frequency and intensity in extreme events** • **Milder winters**	• Decreased moisture stress • New crop rotation • Early maturation dates • Longer and warmer growing season • Enhanced plant production from increased CO_2 levels[12]	• Crop damage from heat • Increased moisture losses • Soil degradation • Increase in floods and/or droughts • Increased disease/weed/pest infestations

Source: Adapted from Lemmen et al. (2008) and Sauchyn and Kulshreshtha (2008)

It is important to point out that the impact of the changes in climatic conditions on agriculture productivity and economic conditions depend heavily on the adaptation measures that are taken. Assessing the possible and ongoing adaptation strategies is a growing field of research and will be reviewed in the next section.

[12] Based on laboratory experiments.

3.4 Approaches to Measure Impact of Adaptation to Climate Change on Agriculture

3.4.1 Early Approaches

The early research that focused on the weather effects on agriculture was mainly concerned with its impacts on yields over time. Research by Smith (1907) examined weather-yield relationships in Ohio using data obtained from U.S. Weather Bureau. In this study, corn yield and rainfall in June, July and August in the U.S Corn Belt from 1888 to 1902 were used. It was concluded that rainfall in July was the most important factor for corn yield; more than five inches of rain increased yields significantly. After this seminal work, much more research has been done concerning the impacts of weather, particularly on crops in the U.S. However, much of this work was done on a large spatial scale and so results varied (see Adams et al., 1990, 1995; Andresen et al., 2001; Easterling et al., 1993; Tannurra et al., 2008). Davis and Harrell (1942) used complex statistical tools to analyze the relationship between crop yields and weather. They found that the distribution of rainfall is important in nearly all areas of the Corn Belt. They also discovered that there was an ideal temperature during certain months that benefited corn yield and any temperature above that maximum was detrimental to yields (Davis & Harrell, 1942)

One of the most important and influential researchers regarding weather impacts on crop yields was Thompson (various studies covering 1963 to 1988). Thompson published many papers on the impact of weather on yields of various crops mostly in the United States and the Canadian prairies. Much of the more recent research follows this methodology. Here a time trend was used to account for technology as well as squared terms and interaction terms to account for non-linearity of weather variables (Thompson, 1962, 1963, 1969, 1970, 1985, 1986, 1988; Tannurra et al., 2008). Thompson (1975) looked at how a cooling trend as well as a warming trend would affect future agriculture production. His major conclusion was that weather fluctuations are one of the major causes of yield variations in crops around the world. He also showed that spring wheat in Canada is positively affected by lower than normal temperatures but year to year fluctuations in yields in Canada were greater than those in the U.S. (Thompson, 1975). The major conclusion of Thompson (1975) was related to cooling, such that the highest yields are observed when weather is near normal or slightly cooler for a majority of crops grown in the northern latitudes; therefore a slight cooling would be beneficial but a warming trend could have detrimental effects on crop yields in Northern U.S. crop producing regions.

This early literature focused mainly on the impact of climate on crop yields. Although this work was seminal in understanding the effects of weather on different crops, it did not account for all the decisions and inputs that went into crop production. It was therefore important to understand how these different aspects, most notably adaptation decisions, impacted production. This opened up a new area of research that focused on assessing how farmers were adapting to a different climate. These studies, as discussed in the next section, have involved several types of methods, such as agro-economic models, Ricardian models and discrete choice models.

3.4.2 Agro-Economic Models

The basis of agro-economic models was to include social variables that would determine the nature of adjustments that farmers were making in response to climate. Most of the previous research used existing climate models but added in social determinants to bridge the gap between both these fields of research. A study by Kaufmann and Snell (1997) was one of the first to develop a hybrid model to assess the effect of adaptation to climate change. They accomplished this by using a pooled cross-sectional model with climatic variables, economic environment (socials conditions that influence management decisions, purchased inputs) and technical/scale variables (size of farms, level of technology, quality of land planted) to explain changes in yield of corn across the U.S Grain Belt. The results proved that yield is determined by both social and climate factors. The model also explained that farmers changed their crop mix in reaction to changing social factors, such as farm programs or loan rates.

In a study in the MINK (Missouri, Iowa, Nebraska, Kansas) region of the U.S., Easterling et al. (1993) also studied the impacts and responses to climate change. Using an existing simulation model (EPIC), they distinguished between cumulative and long- term responses to climate change including adaptations (long term research and changes in policy), and short-term responses including adjustments (low cost, currently available responses). They used a modified simulation model for each scenario under an analog climate representing the 1930s. This climate was used to assess how each scenario would differ under economic conditions prevailing in 1984/87 and then in a future scenario in 2030. The results of the simulation suggested that the warming would be severe enough to affect all crops in the region except wheat and alfalfa, even when possible CO_2 enrichment is considered[13]. The demand for irrigation in these areas would also increase. However, assuming future technological change and other adaptation strategies that would likely be present in the future, they found that yields would remain relatively the same in the long term. Short-term adjustment, however, would have little effect on ameliorating the damage caused by a changing climate in the future scenario.

This initial research assessing adaptation and economic impacts of climate change were useful, but lacked proper representation of the farmer. Because these studies represented the 'naive' farmer – one who did not take a wide set of adaptation strategies – it over estimated the losses from climate change (Mendelsohn & Reinsborough, 2007). There are various forms of adaptation that could be made by the farmer, including changing crop mix and/or cultivars or even changing the use of the land altogether (Brklacich and Stewart 1995; Brklacich et al. 1997; Weber & Hauer, 2003). The next model

[13] CO_2 levels in the atmosphere have been steadily climbing and are expected to continue to do so. CO_2 is an essential input to plant life as it stimulates plant growth. Most studies have concluded an increase in this compound in the atmosphere enriches plant development, this increasing yield substantially and favourably (see Rogers & Dahlman, 1993).

attempted to capture these numerous changes, particularly that of crop switching, that was available to farmers.

3.4.3 Ricardian Models

The Ricardian model was developed to better represent farmers and the potential crop switching adaptation strategies that they would be likely to employ. Mendelsohn, Nordhaus and Shaw (MNS) (1994) pioneered this new model, named after the economist David Ricardo (1772 -1823) because of his original observation that land rents would reflect the net productivity of farmland (Mendelsohn & Reinsborough, 2007). The method uses climatic and non-climatic variables to explain changes in the value of farmland or the income generated by the farm. The benefit of this method compared to the previous methods is that adaptation methods could be inferred from the results. Farmers are assumed to be profit maximizers and will therefore choose the crop mix that meets this assumption. It assumes that farmers' first take climate as given, then decide what to grow, with what inputs, and in what way, or decide to convert land to other uses entirely (Reinsborough, 2003). This encompasses various kinds of adaptation methods, without assuming only the 'naïve' farmer (MNS, 1996).

In the MNS (1994) study, the authors used U.S. county level data from the lower 48 states to measure the impact of climate on land values. Because of the complexity and size of their study, they used spatial statistical analysis to link all the data and employed a weighting scheme on two different dependent variables – crop land value and crop revenue value. The climate variables were represented by average of monthly climatic normals for the previous 30 years. Other explanatory variables included land characteristics such as salinity, slope and moisture capacity. Using the results of the initial estimation, projections on the impact of a changing future temperature were then made. The two models showed quite divergent results, with the crop land model resulting in a loss in land value from warming ranging from $119 billion to $141 billion and the crop revenue model indicating an increase of $25 to $35 million (MNS, 1994). The results suggest that limiting analysis to only major grains may exaggerate the negative impacts of climate change by not taking into account the plethora of other crops (such as warm season crops).

Although the Ricardian model has been applied exclusively in developing countries and in the U.S., it has had a limited number of studies in Canada. There have been two published studies done concerning the impact of climate change on Canadian agriculture using the Ricardian model. Reinsborough (2003) used cross-sectional data from the 1996 census to estimate these impacts on agriculture all across Canada. Because of the large spatial scale and complexity, a geographical information system (GIS) was used to format the data. Because it was also difficult to make the distinction between livestock and crop farming, revenues were combined to reflect total farm value. Climatic and land characteristics were included as explanatory variables and due to the large spatial scale, latitude, longitude and elevation data were also used. Due to the nature of the rural population, Reinsborough included migration rates, population density and income to make up the socio-economic variables. The findings suggest that Canada would benefit greatly from increased temperature and precipitation[14], although like MNS (1994), there are large deviations in the results from land values and farm revenues. Using farmland value as the dependent variable resulted in an increase in farmland value of $985 thousand and using farm revenue resulted in an increase of nearly $1.5 million.

Weber and Hauer (2003) conducted a similar study using all Canadian agriculture regions and census data from the 1996 census. Typical measures of climate and soil characteristics were used, as well as regional control binary variables for all the provinces. To avoid the extreme land values associated with land close to metropolitan areas, such as Vancouver and Toronto, these values were

[14] Reinsborough (2003) assumed that temperatures and precipitation across Canada increased uniformly by 2.8°C and 8%, respectively. However, as mentioned, it is highly unlikely that this change will be uniform across Canada.

removed from the final data set. However, average dwelling value was used as a proxy for urbanization to pick up the changing rural population in other provinces. The results from the study showed that an increase in climate[15] would be beneficial to Canada, most notably in the prairies due to the longer and warmer growing season. The prairies would see the highest land value increase, up 78% by 2051; with the remaining provinces each between one and seven percent. An important comment that was made by Weber and Hauer (2003) is that the Ricardian approach has the potential to overestimate the benefits of climate change on agriculture – that is, the influence of the sum is greater than the individual parts. For example, while crops migrate easily within the same geoclimatic zone, there are barriers such as different land characteristics and technology across large regions (such as the Prairies) (Adams et al., 1999).

Another more recent study by Amiraslany (2010) used the Ricardian model to estimate the impact of climate change on land values in the Prairie Provinces. Amiraslany (2010) employed a fine spatial scale (Census Sub Divisions) and estimated multiple panel data models. Various measures of climate were used in the model specification including temperature, rainfall, snowfall, frost free days, growing degree days and evapotranspiration. Socio-economic variables included income, migration and population density. One of the greatest contributions made in this study was the inclusion of prices. Using area response functions for wheat and canola, Amiraslany (2010) was able to simulate land value changes under future climate change as well as future price conditions. Like previous Ricardian studies done in Canada, Amiraslany (2010) found climate change to be beneficial to the Prairies (except for some southeast regions of Alberta); the impact of climate and price changes increased farmland value by up to 51 percent. However, it highlighted the importance of precipitation as the Prairies are very vulnerable to water scarcity and land use and land values strongly depend on precipitation (Amiraslany,

[15] Increase or increased climate is referred to as an increase in average precipitation and temperature for the remainder of this thesis.

2010). Although Amiraslany (2010) specifically assessed the impact of climate change on land values in the Prairie Provinces using panel data as well as including price effects, this research only focused on the area response of two major commodities produced in the Prairies - - wheat and canola.

The Ricardian model gave researchers the opportunity to include several adaptation measures to climate change in their research. However this method still suffered from weaknesses, most notably not being able to account for price effects (with the exception of Amiraslany (2010)). According to Polsky (2004), although the premise of the model is based on perfect competition and therefore postulates that prices have reached equilibrium, MNS (1994) have stated that the model could be better adapted to include price effects. Another weakness of the Ricardian model is that interpretation of adaptation is based solely on the researcher. Farmers are also assumed to respond seamlessly and costlessly to climate change using technologies that are presumed to be accessible to all farmers at any given point in time. However, in reality adaptation is an ongoing and potentially costly process (Gbetibouo & Hassan, 2005; MNS, 1996). These assumptions made it difficult to properly predict how farmers would make their decisions in light of the uncertainty faced by climate change. Therefore there was a need to better understand how adaptation was being undertaken and how it may influence future production decisions.

3.4.4 Discrete Choice Models by Individuals

Seo and Mendelsohn (2009) were the first to develop a 'structural' Ricardian model that would explicitly model the underlying decisions by farmers. The basic formulation of the 'structural' Ricardian model was a discrete choice problem. This formulation had the advantage of showing exactly how adaptation was taken as the dependent variable showing it as a choice among alternatives. Discrete choice models are often used in literature where the decision maker is faced with such a problem. A common choice model that is used is the Multinomial Logit (MNL) model. The MNL model allows a choice between multiple alternatives; such is the case in marketing, transportation and agriculture. This model is important to this area of research, as it can be a predictor of supply response when crop choice is used as the dependent variable.

The work by Seo and Mendelsohn (2009) is an example of how a discrete choice model can be used to analyze adaptation on farms in South America. Using a survey that asked detailed questions for a given farming year, the authors were able to estimate how climate and other factors impacted the crops that each farmer chose to grow in that year. The survey was administered in seven countries across South America and the results suggested that farmers chose the crop that fit their local climate. Other factors that significantly influenced crop choice included type of soil, price of commodity and the education of the household. Using simulation techniques, Seo and Mendelsohn (2009) showed that crop switching is likely to occur under different climate scenarios (as a form of adaptation). Similar applications of the MNL model in developing countries are presented by Mendelsohn and Seo (2007), Kurukulasuriya and Mendelsohn (2008) and Deressa et al. (2009).

Although the discrete choice model has been used primarily in developing countries, the information is readily available in most countries. In Canada, this method has been applied very sparingly, as only one agricultural example was found (Krakar & Paddock, 1985). Krakar and Paddock (1985) used summerfallow plus seven major crop groups (mainly grains, canola and flaxseed) to estimate supply response. Using a system of equations allowed the authors to distinguish among variables that influence crop choice, as well as the decision between the Canadian Wheat Board (CWB) and open market (non-CWB) cropping decisions. The dependent variable was represented by a series of acreage demand equations and explanatory variables that included CWB and farm prices, costs of production, hog inventories and a binary variable for the Lower Inventory For Tomorrow (LIFT) program. They found that initial prices (those announced for CWB commodities before spring planting) had an important impact on initial planting decisions and were therefore important to farmers' crop allocation decisions (Krakar & Paddock, 1985).

Although Krakar and Paddock (1985) used historical information to gauge supply response of various crops in the Prairies Provinces, they did not account for climatic influences. The discussed discrete choice models use only cross-sectional data covering one crop year. One of the major impacts of climate change is increased climate variability and frequency of extreme events. Such events may have a dampening effect on the farm economy (including land value) not only for the current period but also for subsequent periods. The discrete choice method has also not yet been applied to the Prairie Provinces. Due to the random utility theory underlying discrete choice models such as the multinomial logit model, it cannot be used with aggregate data or in a context where the dependent variable is measured as share or percent, which limits its application.

3.4.5 Discrete Choice Model for Aggregate Data

A method of discrete choice modeling has recently been developed that allows for aggregate data and a dependent variable that is represented by a share or percentage. These types of observations are common in financial, agricultural and transportation literature. Papke and Wooldridge (1996) initially used this model with cross-sectional data to analyze participation rates in a 401(k) plan[16]. Papke and Wooldridge (2008) employed the same framework to assess middle school test scores using panel data. This model is referred to as the fractional multinomial logit (FMNL) model. Since this seminal work, the method has been used in a variety of situations, including applications to agriculture (Ding et al., 2008; Mu & McCarl, 2011; Yin et al., 2010).

[16] A 401(k) plan is a 'tax-deferred' savings account set up by employers where eligible employees can defer salary or wages to saving for retirement in the U.S. Employers may also match this deferral (Investopedia, 2013).

Ding et al. (2008) used the FMNL model to analyze farmers' adoption of different tillage practices (no till, conservation, conventional and reduced) using county level data from Iowa, Nebraska and South Dakota. The authors proposed that the ability to adapt to a changing climate could be done by choosing amongst various tillage practices. This adaptation choice would depend on factors such as precipitation shocks (i.e. floods and droughts), insurance and fuel prices, and land characteristics (Ding et al., 2009). Their findings indicate that a farmer would change tillage practices when there is abnormally dry weather, but wet weather seemed to have no impact on tillage choice.

Mu & McCarl (2011) examined how farmers' adapt to climate change with a given set of options between livestock and crops in Iowa, Nebraska and South Dakota using the FMNL model. Using the percent of land under crop, pasture or other uses, Mu & McCarl (2011) used census level data from 1978 to 2008 to determine how land allocation has changed over time. Because pasture is usually used in cattle operations they included market values of crop and livestock, as well as on-farm beef inventories and a cattle stocking variable. Various climate measures were used including 30 year monthly precipitation and temperature averages as well the Palmer Drought Severity Index (PDSI) and a precipitation intensity index. The results from this study showed that as winter and spring precipitation and temperature increase, more land is allocated for pastureland.

Yin et al. (2010) looked at how land use has been changing over the years in one of China's largest agricultural regions, the Upper Yangtze Basin. Data on land use shares were derived from satellite imaging. Total area was segmented into four categories – cropland, forestland, pastureland and other. These were used as the dependent variables. The model also included various prices and costs to represent the economic explanations for land use, as well as socio-economic factors, land characteristics and regional binary variables to represent the heterogeneity between counties. The findings showed that land use decisions were initially made to capture immediate profits, but they were not significantly influenced by long-term price signals (these prices being mostly distorted) (Yin et al., 2010). Yin et al. (2010) concluded that regional policies and institutional factors play a major role in land use. This led to their recommendation that local governments should play a more active role in the agriculture sector of this region.

3.5 Conclusion

The first part of this chapter focused on the literature concerning supply response and its relevance in studying farmers' choice of crop mix. The major weakness concerning supply response was its inability to capture the role of climatic variability in farmers' response to area allocation decisions. After a brief review of the potential impacts of climate change on Saskatchewan agriculture, section 3.4 outline the literature pertaining to adaptation in agriculture to these changes. The agro-economic models were one of the first types of models that were developed to account for adaptation to climate change; however they did not allow for multiple adaptations by farmers. The Ricardian method allowed the models to capture the farmer making adaptation decisions in the face of climate change, but these methods often fail to include the effect of commodity prices on this decision, except for Amiraslany (2010). Another weakness was that interpretation of adaption was implicit, with explanation based solely on the researcher. The use of discrete choice models allowed researchers to include a price measure as well as explicitly modeling adaptation measures by individual farmers. However, they could not be used with aggregate data where the dependent variable is a fraction. The FMNL model was developed to address these two issues. Given its previous applications and its desirable characteristics, this model is the most appropriate model to use in order to quantify crop choice decisions in Saskatchewan agriculture.

CHAPTER 4:

CONCEPTUAL MODEL

4.1 Introduction

The previous chapter reviewed various models that have been used to quantify the importance of adaptation to prevent the negative economic impacts of climate change. From the review and the nature of this research it was evident that a choice model would be the best way to model crop choice as an adaptation strategy for the following reasons: one, this approach allows one to identify crop choice explicitly using aggregate level data; two, since it is based on standard choice theory, it has the benefits of discrete choice experiments. However, this model has had a very limited application and very few studies have been conducted in the context of agricultural decision making. To date there is no known application of this type of model in Canada. Therefore, this chapter will draw upon other models in order to assess the important variables that should be included in this study to deal with choice of crops as an adaptation strategy to climate change.

This chapter is organized as follows. Section 4.2 discusses the theory supporting the FMNL model. As the FMNL model is a variant of the MNL model, the MNL is reviewed briefly. This section describes the objective of the FMNL model and expands on the manner in which it could be used in an agriculture context to measure adaptation. Section 4.3 reviews the variables that are important to include when addressing adaptation to climate change in agriculture. Four important categories of variables have been outlined – climatic, economic, geographic and socio-economic (policy). Each of these categories is discussed in detail in section 4.4, followed by a summary of the chapter in section 4.5.

4.2 Theory of Discrete Choice

4.2.1 Theory of Economic Choice

Using choice models is an ideal way to analyze decision making in various fields of research. The MNL model has been employed in various studies done in developing countries looking at the adaptation process in agricultural regions (see Deressa et al., 2009; Kurukulasuriya & Mendelsohn, 2008; Seo & Mendelsohn, 2009). The MNL model is used when there are multiple choices available to the decision maker, as was the case in developing countries where a multitude of crops are grown. However, because of the random utility theory underlying this choice model in-depth interviews are always employed in the research, with subsequent aggregation. The choice could also only take on a value of zero or one, otherwise estimation is not possible.

Although this model has many of the desired characteristics needed when addressing adaptation, the underlying random utility (RUM) theory supporting it makes it impossible to use aggregate level data. Furthermore, it cannot be used when dealing with shares or percentage values as the dependent variable. There are many situations where these measures are very common, such as in disciplines of finance, television ratings and agriculture (Papke & Wooldridge, 2008). Papke & Wooldridge (1996) extended the multinomial logit model to include a dependent variable that was measured as a share or percentage, applying the FMNL. Similarly to the MNL model, the FMNL model allows the dependent variable to take on a value between zero and one.

Multinomial Logit (MNL) Model

To begin, it is necessary to cover the underlying assumption of the MNL model, as described by Seo & Mendelsohn (2009). Although the RUM does not apply to aggregate level data, it is important to show the underlying assumption of this choice model. Farmers are assumed to be profit maximizers' and will therefore allocate land to the highest valued crops to maximize profit (∏)(Seo & Mendelsohn, 2009). This can be shown mathematically as[17]:

$$\prod_{it} = V_{it}\ (K_{it}, S_{it}) + \varepsilon_{it}(K_{it}, S_{it}) \tag{4.1}$$

Where K are characteristics that are exogenous to the farm (such as climate, land characteristics and prices); and S represent the characteristics of the farmer such as age, credit etc. The subscripts *i* and *t* represent the cross-sectional and time series components, respectively. V represents the coefficient vector and ε is the error term. Farmers' will choose the crop (or crop group if the choices are too abundant) that maximises this objective function. Thus one can define Z=(K,S), and the farmer will choose crop *j* over all other crops, *k* if:

$$\prod{}^*_{ij}(Z_i) > \prod{}^*_{ik}\ (Z_i) \tag{4.2}$$

More simply, crop *j* will be chosen over all other crops, *k* if the expected profit of crop *j* is greater than all other crops over the time period. This overview of the MNL helps set up the discussion of the extended FMNL model that is discussed next.

Fractional Multinomial Logit (FMNL) Model

Mathematically, Y_{it} represents the fraction or share of the desired dependent variable that is used where *i (i=1,2,3…I)* represents the cross-sectional variables (i.e crop districts) in the equations and *t (t=1,2,3…T)* is the time series component. For the level of aggregation it must hold that:

$$0 \le Y_{it} \le 1 \qquad \textstyle\sum_i Y_{it} = 1 \tag{4.3}$$
$$\text{For all } t\text{'s.}$$

Because Y_{it} is bounded between zero and one, using linear methods could generate fitted values that fall outside this unit interval. To avoid this result, the problem can be modeled using a logistic function (Yin et al., 2010).

[17] Adjusted to fit panel data.

$$E(Y_{it} \mid X_{it}) = p_{it} = \frac{\exp(X_{it}\beta_k)}{1 + \exp(X_{it}\beta_k)} \qquad (4.4)^{18}$$

Thus:

$$Y_{it} = \frac{\exp(X_{it}\beta_k)}{1 + \exp(X_{it}\beta_k)} + \varepsilon_{it} \qquad (4.5)$$

Where β_k is the coefficient vector and ε_{it} is the independently and identically distributed error term. The asymptotic analysis is carried out as $N \rightarrow \infty$ and for all of i,

$$E(Y_{it} \mid x_{it}) = G(x_{it}\beta) \qquad (4.6)$$

Where $G(\bullet)$ ($i = 1, 2, \ldots, I$) is a predetermined function whose properties ensure that the predicted fraction will lie in the interval (0, 1) and will sum to one across all i (Sivakumar & Bhat, 2002). The most common cumulative distribution function chose for $G(\bullet)$ is the logistic function. This can be estimated using nonlinear least squares (NLS); however heteroscedasticity is likely to be present since the variance of Y_{it} conditional on x_{it} is unlikely to be constant when $0 \leq y_{it} \leq 1$. Therefore the NLS estimates will not have any efficiency properties (Papke & Wooldridge, 1996).

The estimation procedure proposed by Papke & Wooldridge (1996) is quasi-likelihood method adapted from Gourieroux et al. (1984) and McCullagh and Nelder (1989). The log-likelihood function can be expressed as follows:

$$l_i(\mathbf{b}) \equiv Y_i \log[G(\mathbf{x}_i\mathbf{b})] + (1-Y_i)\log[1-G(\mathbf{x}_i\mathbf{b})] \qquad (4.7)$$

Maximizing this equation is straightforward and because it is a member of the linear exponential family (LEF) the β's obtained in estimations are consistent and asymptotic normality distributed (Papke & Wooldridge, 1996; Sivakumar & Bhat, 2002).

[18] Where 'exp' signifies that ($X_{it}\beta_k$) is a power function and 'p_{it}' is the percent measure of the dependent variable.

A fractional logit equation needs to be established for each dependent variable; to ensure the identification of these equations, only *k – 1* equations are estimated (Yin et al. 2010). The equation that is not estimated serves as the base or comparison, with results from each estimated equation representing the choice over the base. The effect of the explanatory variables on the base choice equals one minus the sum of the effects on the other *k-1* equations.

4.2.2 Application of FMNL Model to Agriculture

Shares or percentages are common in agriculture. Examples include, share of land under different tillage practices or share of land allocated to specific crops. To date, this model has been used in agriculture by only a few studies. One of these studies focused on how farmers adapt to climate by switching between crop and livestock (Mu & McCarl, 2011), while the other focused on an analysis of adoption of different tillage practices (Ding et al., 2009). Both papers used county level data from the Midwest agriculture producing regions of the United States. The data were obtained from secondary sources, which is very common to find in developed countries through private or government organizations such as the United States Department of Agriculture. The third published paper by Yin et al. (2010) focused on a large agricultural producing region in China and examined how land use had changed in that region over a 25 year period. An interesting aspect of this paper was how the dependent variable was measured. Although it was still represented as a share of total land use, it was derived from satellite imaging since accurate data on land use in not available in that country.

From the above examples it is clear that the FMNL model can have a wide application to agriculture. It also has the advantage that it can be used without having to conduct a survey which can be costly and time consuming. Particularly in developed countries data are available through various organizations and although it is at an aggregate level compared to a micro level, research suggests aggregate models are superior to the micro model in predicting acreage response (Wu & Adams, 2002).

The next section will describe the functional form that the FMNL model will follow when applied to agriculture research.

4.3 Conceptual Functional Form

Due to the limited application of the FMNL model in agriculture, in this study many of the relevant variables were identified using past research related to farmer's decisions regarding crop choice. Based on the literature review discussed in chapter three, four categories of explanatory variables are important to include when analyzing crop choice as an adaptation strategy to climate change. These categories are: climatic, economic, geographic (spatial) and socio-economic (including policy). In other words, choice of a given crop by producers in a region is determined by equation 4.8.

$$\text{Choice} = f(\text{Climatic, Socio-economic and Policy, Geographic or Spatial variables}) \tag{4.8}$$

Examples of the types of variables to include in each of the four categories are described in the next section.

4.4 Discussion of Variables

4.4.1 Climatic Variables

As discussed in chapter three, early research concerning the impact of climate change on crop production focused on how yields of crops are influenced by weather variability. It has been widely demonstrated and accepted that climatic variables have a nonlinear relationship with crop yields. More specifically they exhibit a hill shaped relationship, with a maximum amount of precipitation or temperature being ideal, and after that increased levels of temperature or precipitation are harmful to yields (Schenkler & Roberts et al., 2008). This relationship is relevant over the growing season as warm temperatures and increased moisture during planting and development are beneficial to the crop up to certain thresholds, whereas these same conditions during maturation can result in heat blast and/or increased disease spread (from wet conditions). Therefore the squared terms of these variables are expected to have a negative coefficient. Figure 4.1 depicts the relationship between yield and climate (precipitation and temperature) where yields increase up to a certain point (Y_{max}), and after that point, higher values of temperature or precipitation are damaging to the crop, thereby decreasing the yield.

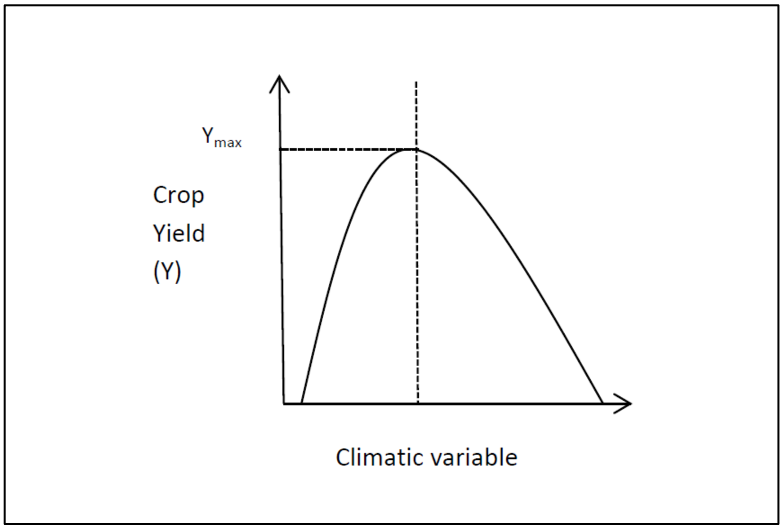


Figure 4.1: Impact of Climatic Variables on Yield

Another important climate measure used in research is the interaction between precipitation and temperature (Weber & Hauer, 2003). Multiplying the temperature by the precipitation for the same period has been used to provide this interaction. For example, precipitation in April would be multiplied by temperature in April to generate this term. Together, this term would represent the impact total climate had in this month. This further exemplifies the impact of increase in climatic variables on crop yield. In Canadian research, these interaction terms are usually expected to have a negative impact on the crop as excessive moisture and heat through the growing season is not beneficial to plant development (Weber & Hauer, 2003). An exception is when fall climate variables are used, the result may be beneficial. A positive coefficient implies a longer growing season without the negative impact of an early frost.

A common way to represent these climate variables is by using monthly average of total precipitation and mean temperature. In Canadian studies, due to the short growing season and the absence of multiple crops within a year, only data from the growing season months have been used by most studies.   These months are usually from May to October; however it has been shown that using consecutive months increases the issue of multicollinearity (Tannura et al., 2008). More common representation is given by using a month to represent each season such as January (winter), April (spring), July (summer) and October (fall). This is also preferred when studying crops that are seeded in the fall and grow over the winter months, as well as accounting for the precipitation accumulated through the winter.

Another common way to measure climate, specifically temperature, is by using growing degree-days and/or crop heat units. Schenkler et al. (2004) define degree-days as the sum of degrees above a lower baseline and below an upper threshold during the growing season. This gives a more detailed representation of temperature as daily values are used to create this variable. Various studies in the U.S have used this measure including Schenkler et al. (2004), Deschênes & Greenstone (2007) and Polsky (2008). Examples of this measurement used in Canada include Cabbas et al. (2009) and Weersink et al. (2010). Both of these studies used the production function approach using both linear and non-linear measures, with both being significant and having the expected signs (positive linear, negative non-linear). This further clarifies the importance of temperature beyond a maximum being detrimental to plant development.

In some cases, climate variables alone cannot explain the change in crop yields or production and other measures of climate need to be included. Most of these climate variables are used to pick up the variations in climate that account for extremely wet years or extremely dry years. The Palmer Drought Severity Index (PDSI) is one example of a parameter that has been used in North American climate change literature (see Ding et al., 2009; Mu & McCarl, 2011). This variable is sometimes available through a government or private organization or can be constructed to match the given spatial scale and measurement. Furthermore, it can be constructed to represent the four seasons.

Other ways that are less common to measure climate include using binary variables to show when the observed climate variable is above the median (Weber & Hauer, 2003) or to construct indices. Various other indexes can be constructed to represent climate variability, such as precipitation intensity or index of drought intensity (see Ding et al., 2009; Boubacar, 2010; Mu & McCarl, 2011). Other ways to measure climate variability include: (i) use deviations in monthly averages (Huang & Khanna, 2010); (ii) use average diurnal range (MNS, 1994; MNS, 1996); and (iii) use elevation as a proxy for this measurement (Reinsborough, 2003). Other measures can also include humidity measures (Mu & McCarl, 2011), solar radiation (MSN, 1996; Reinsborough, 2003) and evapotranspiration rates (Andreson et al., 2001).

4.4.2 Economic Variables

The major economic variable influencing acreage allocation is prices of commodities. Agriculture commodity prices are some of the most volatile market prices and can lead to the producer taking on additional risk. Nerlove (1965) hypothesized that farmers would take into account this risk when choosing which crops to grow. His research showed that farmers respond very little to current prices, and pay more attention to past prices (Nerlove, 1965). Nerlove (1965) suggested farmers act in response to expected prices when deciding what to grow for the crop year. In past studies, expected price was calculated using previous years' prices and constructing a weighted moving average transformation.

Although the work by Nerlove established that expected prices play a significant role in acreage allocation decisions, their interpretation has varied over the years. One simple way to do this is to use the lag of a commodity price under the assumption that farmers make decisions based on historical information and trends. Most studies have used a simple one period lag depending on the price information used (Bailey & Womack, 1985). However, other studies have used multiple period lags (Krakar & Paddock, 1985) which can be estimated by statistical software. Another variant that can be employed as expected price is futures prices. Gardner (1976) suggested this method by using it to estimate soybean production in the U.S. Futures prices have also been used more recently in acreage response studies (see Chavas & Holt, 1990, Wu & Adams, 2001; Lin & Dismukes, 2007). The resurgence may be attributed to tools such as the Internet and the availability of price information that are now readily available to farmers. However, most of this research is done in the U.S. where a majority of the crops are marketed on the open market. The final type of price expectation that is important is the use of a moving average of past prices. The equation used to calculate a moving average can range from being simple to very complex in some instances. For simplicity, Table 4.2 shows various supply response studies and measurement of expected prices.

Table 4.2: Supply response studies and different measures of expected price

Study	Measure of expected price	Country being studied
Bailey & Womack (1985)	Lagged prices	United States
Chavas & Holt (1990)	Futures and cash prices	United States
Krakar & Paddock (1985)	Lagged prices	Canada
Lee & Helmberger (1985)	Lagged prices	United States
Clark & Klein (1992)	Lagged prices	Canada
Chavas & Holt (1990)	Weighted average of past prices	United States
Meilke & Weersink (1990)	Lagged price divided by farm input price index	Canada
Massow & Weersink (1993)	Weighted average of past prices	Canada (Eastern Ontario)
Wu & Adams (2001)	Futures prices	United States
Lin & Dismukes (2007)	Futures prices	United States

Although economic variables are an integral part of agriculture research, there have been few studies that have included prices when analysing the impact of climate change on acreage allocation. For example, the Ricardian model estimates how farmland value will change under different climate scenarios; however one of its major weaknesses is that it ignores the effect of market prices. It has been argued that in equilibrium, prices will not affect farmland value (MNS, 1994). However, MNS (1994) do acknowledge that the model could be improved by including some representation of prices. One of the advantages that the choice models have over the Ricardian method is that they are able to include a price effect. The studies that have included price are by Mendelsohn and Seo (2007) and Kurukulasuriya and Mendelsohn (2008). These studies have employed current year's price of the principal crops used in estimation, which is considered a naïve way of representing prices influence crop choice.

4.4.3 Socio-Economic (Policy) Variable

In micro-level studies of crop choice, past studies have used two types of variables – one related to characteristics of the decision maker (called socio-economic variables), and change in the policy regime that may affect the crop choice decisions. On the first set of factors, there have been multiple studies of possible adaptation strategies in the agriculture sector to avoid the negative impacts of climate change (see Howden et al., 2007; Mendelsohn, 2000; Morton, 2007). As Bryant et al. (2000) points out, adaptive responses can be taken at the farm level, collectively from a community or by a particular agriculture sector. Some of the first work linking climatic and socio-economic indicators to crop production was done by Easterling et al. (1993). This study used a simulated crop model to gauge how a specific adaptation measure to climate change would impact crop production. However, these results assumed farmers' would take only the given adaptation of crop rotation between corn and sorghum. In this case, the socio-economic factor was small and assumed by the researchers, when in reality there are more crop rotations, as well as farmer characteristics that could influence adaptation.

Kauffman & Snell (1997) was one of the first studies to integrate climate and multiple socio-economic variables into a yield model for corn in the U.S. This study bridged the gap between yield models and previous adaptation literature by including loan rates available to farmers, value of farm machinery, average farm size, and percentage change in seeded acreage from the previous year. Their findings concluded that in fact these social determinants account for a significant part of the changes in yield. Bradshaw et al. (2004) examined crop diversification specifically as an adaptation to climate change by analyzing average number of crops by small farm versus large farm in the Canadian prairies. They found that smaller farms have a more diversified crop portfolio, and could potentially adapt well to a changing climate.

In the supply response literature one could argue that the incorporation of risk is a proxy for social characteristics. Using production theory to estimate the influence of risk on farmers' acreage allocation decisions involves estimating a wealth effect. This can be used as a gauge of whether a producer is risk averse or risk neutral -- a characteristic of the farmer. A decision maker who is risk averse will be influenced by risk when allocating resources, for example, land. As supply response research expanded over the years, different measures of risk have been used. However a common denominator is wealth or income (see Chavas & Holt, 1990; von Massow & Weersink, 1993, Lin & Dismukes, 2007). Although these studies are usually highly aggregated as well as strictly time series, they portray the importance of farmers' characteristics to acreage allocation decisions.

The more recent literature linking socio-economic variables to adaptation to climate change are the Ricardian and choice models. In developing countries, this emphasis was on adaptation at the individual level. A majority of these studies used characteristics of the individual farmer being interviewed such as: age, access to credit, number of family members, male or female, education level, access to electricity, uses of computer etc. These were then aggregated to represent a specific area (see Liu et al., 2004; Mendelsohn et al., 2006; Seo & Mendelsohn 2007). The studies done in developed countries, such as the U.S and Canada, have focused on the characteristics of the area under study rather than of the farmer. These measurements included accounting for population, per capita income, and migration rate to cities or population density (see Mendelsohn & Dinar, 2003; Mendelsohn & Reinsborough, 2007; Reinsborough, 2003; Weber & Hauer, 2003). For aggregate data based studies, individual farm level characteristics are not feasible and therefore more emphasis was placed on policy related changes affecting crop choices.

Because of the risk associated with commodity prices, policies have been developed to help lessen this risk for both the farmers and the consumers. Canada has an extensive history of farm support programs with many commodities receiving some form of price support. However not all commodities are treated equally. Much of the acreage response literature focused on incorporating these policies into the price variables. Most notably in Canada is the existence of the Canadian Wheat Board (CWB). For the crops grown under the jurisdiction of the CWB, an initial price is announced before spring seeding. The announcement of this price has been shown to influence acreage allocation decisions as pointed out by Krakar & Paddock (1985) and Clark & Klein (1992).

Some policies have only a limited period of time in which they were present. These include policies in Canada such as LIFT (Lower Inventory For Tomorrow), PCP (Permanent Cover Program), GRIP (Gross Revenue Insurance Plan) and WGSP (Western Grains Stabilization Plan). Programs such as these were implemented for only a few years before being discontinued but still had a significant impact on acreage allocation. Some programs also could not be incorporated into prices because they did not directly impact farm prices (PCP for example). For that reason they are usually represented by a dummy variable (see Krakar & Paddock, 1985; Clark & Klein, 1992; Clark & Klein, 1996; Smith et al., 2001). However there are a few studies that have projected the impact these policies may have on prices of commodities, such as Meilke & Weersink (1990) did for the WGSA (Western Grain Stabilization Act).

4.4.4 Geographic (Spatial) Variables

Just as different crops are suited to different weather regimes, they are also suited to different geographic factors. The given land characteristics of the area under study will influence the farmers' choice of crops to grow. Depending on the spatial scale, various measurements have been used to account for varying land characteristics. Of the limited studies in Canada, Reinsborough (2003) used two soil characteristics to distinguish different regions – clay and sand. Weber & Grant (2003) improved the model by using the six soil types categorized by the Canadian System of Soil Classification that overlay the country. Highly productive agriculture regions like the prairies and Southern Ontario were better represented by this measure of geography. A smaller scale study by Carew et al. (2009) examined the factors influencing wheat yield in the province of Manitoba, by including a ranking system classifying the most productive and least productive soil areas in the province.

Other geographic variables used in Canadian literature include latitude, elevation (Reinsborough, 2003) and altitude (Mendelsohn & Reinsborough, 2007). The former study used the mentioned variables to account for the more northern regions of the country, where growing seasons are shorter and land is less suitable to agriculture. The latter study compared the U.S and Canada. Instead of using soil characteristics they divided the two countries to distinguish between the northern regions of the U.S, which grows similar crops to Canada, and the southern U.S. However, latitude and solar radiation were found to be highly correlated with climatic variables and therefore created a problem with the estimated coefficients (Weber & Hauer, 2003). Other measures of land characteristics included in North American studies consist of moisture capacity, organic matter content of soil, clay content of soil, amount of flooding, etc. (Mendelsohn & Dinar, 2003; Polsky et al., 2004; Schenkler et al., 2007; Weber & Hauer, 2003). These studies use a large spatial scale, usually covering all of Canada or numerous agriculture production states in the U.S.; and therefore using any other measure of land characteristics could potentially overwhelm the model.

4.5 Conclusion

This chapter has provided a review of the important variables that influence acreage allocation decisions. The FMNL model has not been used extensively in agriculture and to date has not been applied to Canadian agriculture. However, this model has many desirable characteristics to quantify the decisions made by farmers in the choice between crops as an adaptation to climate change. Many of the variables discussed came from other related fields of research. The four groups of variables most commonly used are the climatic, economic, socio-economic and policy, and geographic (spatial) variables. The measurement for these variables also varies between studies, particularly among supply response and adaptation studies. Ideally, this model would be best estimated by including variables that represent each of these groups. It is also significant to note that when dealing with aggregate data in developed countries, socio-economic variables and policy variables overlap slightly. This is due to the fact that farmers in Canada can take advantage of numerous farm programs, which in some cases are voluntary; therefore choice to participate is dependent on the preferences of the individual farmer. Based on the review of literature, in chapter five the empirical model is described in the following chapter.

CHAPTER 5

EMPIRICAL MODEL

5.1 Introduction

This chapter describes the economic model that was used in this thesis to assess adaptation to climate change. The scope of the study is described in section 5.2, followed by the specification of the model in section 5.3. Drawing upon chapter four, the variables being used as the dependent and explanatory variables are discussed in detail in section 5.4. Section 5.5 describes model specification, followed by study data sources including units of measurement and sample size in section 5.6. The estimation procedure used and the possible issues that have been noted in section 5.7 follows this. Section 5.8 provides the simulation methodology, followed by some concluding remarks in the final section

5.2. Scope of the Study

The importance and significance of agriculture in Saskatchewan makes this province an ideal area of Canada to investigate adaptation to climate change. Saskatchewan is very diverse ranging from dry, arid area in the South to lake and tree covered Northern areas. The agriculture production region of Saskatchewan is confined to the Southern part of the province, where tree cover is minimal and land is more conducive to agriculture production. Each corner of the province experiences different weather patterns, such as the warmer and drier conditions in the south, as well as different soil and land characteristics making the province heterogeneous. For that reason the spatial scale for this study was selected at the census of agriculture region (CAR) or crop district (CD) level. A map of the province by CD is shown in Figure 5.1. Some CDs are split into two to three sub districts. In this study the only districts that were split into sub districts were CD one and seven to correspond with the land characteristics. Therefore, the study is based on eleven crop districts in the province. For the simulation (discussed further in section 5.5) the crop districts will be aggregated at the soil zone level. The reason for the difference in spatial scale is due to the collection of agriculture data at the CD level and not by soil zone. However, the CDs line up well with the soil zones. Table 5.1 outlines the crop districts and their corresponding soil zones.

Table 5.1: Crop Districts and Corresponding Soil Zones, Saskatchewan

		SOIL ZONE	
Crop District	**Brown**	**Dark Brown**	**Black**
1a		X	
1b			X
2		X	
3	X		
4	X		
5			X
6		X	
7a	X		
7b		X	
8			X
9			X

5.3 Model Design

The model design will begin with a description of the spatial scale of the study and then move on to describing the variables that were used in estimation. Recall from chapter four equation (4.8):

$$\text{CHOICE}_{it} = f(\text{CL}_{it}, \text{EC}_{it}, \text{SE}_{it}, \text{SR}_{it}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(5.1)}$$

Where, CHOICE is selection of i^{th} crop during period t,

CL represents climate related variables affecting choice of crop,

EC represents economic variables affecting choice of a crop,

SE represents socio-economic (policy) variables affecting choice of a crop, and, SR represents geographical (spatially related) variables affecting choice of a crop.

Each set of variables needs to be identified leading to the specification of the final model. This discussion is provided in the next section.

5.4 Specification and Description of Variables

5.4.1 Dependent Variable Specification

As noted in Chapter 2, Saskatchewan produces a multitude of agricultural crops ranging from traditional grains and oilseeds to fruits and vegetables. However, the commodities that make up a large portion of provincial production are traditional crops, such as wheat and canola. A given farmer can have a choice of a large number of crops. However, in this study the most dominant crops grown were selected and grouped into seven categories to represent the dependent variable.

The dependent variable is measured as a percentage or share of total cropped area within the CD. This was calculated in each crop district as the percentage of total area devoted to a given crop group out of the total cropped area. Table 5.2 shows the aggregation of various individual crops to these seven crop groupings.

Wheat is one of the major crops produced in the province and therefore it was used to represent the first crop group. This group included both durum and spring wheat grown in Saskatchewan. The second group consists solely of canola. Canola was, until recently, one of the only cash crops since it was marketed through open market channels, and thus it provided a good substitute for wheat. The pulse crops represent the third group, which includes peas, lentils and chickpeas. The pulse group is emerging as viable cash crop. Each crop is a sum of the different varieties grown in Saskatchewan, such as red and green lentils, or desi and kabuli chickpeas. Pulses, with the exception of peas, have only recently begun to play a major role in crop production in Saskatchewan. Although lentils and chickpeas have been grown since the early 1980's, their production was minimal and was limited to particular areas of the province. Therefore in the early years of the study period the pulse group was represented only by peas and a small amount by lentils in each CD.

Table 5.2: Specification of Study Crop Groups

Group	Group Name	Crops Included
1.	Wheat	a. Spring wheat b. Durum
2.	Oilseed	a. Canola
3.	Pulses	a. Dry peas b. Lentils c. Chickpeas
4.	Specialty Oilseeds	d. Mustard e. Canary Seed a. Flaxseed
5.	Feed crops	a. Winter wheat b. Fall rye c. Spring rye d. Oats e. Barley
6.	Forages	a. Tame hay b. Improved pasture c. Unimproved pasture
7.	Summerfallow	a. Summerfallow

The fourth crop group is the specialty oilseeds, made up of flax, mustard and canary seed. All three of these crops have been grown in Saskatchewan over the study period, although production has fluctuated and in some years there has been little area devoted to them. Together they account for a significant portion of seeded acreage and thus are treated as one group.

The fifth group is represented by five crops that are grown for feed. Most of these crops were sold either through the CWB or the open market, the majority of them are intended for on or off-farm animal feed. Both types of barley (malting[19] barley and feed barley) were included in this group. Oats are also included in this group, although this crop used to make up a significant portion of seeded area, its area has declined drastically since its removal from the CWB. This change in the policy could be responsible for this decline. Nearly all the oats grown in Saskatchewan are now used on-farm for feed. Although these five crops individually make up a minimal area of seeded acreage, together they account for a large portion of crop area.

The last two groups represent the acreage that is allocated to summerfallow and that to forage. Summerfallow is an important rotation tool and makes up a significant proportion of total land area in each crop district. Forages represent the area that is seeded for hay production or to pastureland for grazing. This group also makes up a significant portion of the total area, since both improved and unimproved pastures are included. As mentioned in chapter two, summerfallow has been steadily declining in the past 30 years, while pastureland has been increasing, however slightly.

5.4.2 Explanatory Variable Specification

i) Climatic Variables

The climatic variable set includes temperature and precipitation regimes in specified CD's of the study. To avoid the multicollinearity problems associated with using consecutive months, the climate variables were represented by four months – January, April, July and October. The winter months (represented by January) are important to include because the crop groupings include two crops seeded in the fall - winter wheat and fall rye. Snowfall in the winter months also influences the soil moisture for spring seeding, thus influencing crop choice. These months also capture the extremes of each season

[19] Malting barley has strict guidelines for acceptance and thus requires much greater skill and management decisions (Government of Saskatchewan, 2010). The seeded acreage to malting barley averages roughly 8,500 acres from 1993-2012 for all of Saskatchewan, representing a minimal amount of acreage (Quality of Western Canadian Malting Barley, 2012).

and the length of the growing season (Weber & Hauer, 2003). Average monthly temperature in degrees Celsius and totally monthly precipitation[20] in millimetres was used as appropriate measure of these variables in Canada. Environment Canada has various weather stations across the province and data from each station are available as monthly averages for every month of the year. Although there are several weather stations in each crop district, data were collected from one centrally located weather station for each crop district. In the case of missing observations, either nearby station data was used or Olympic[21] averages were estimated[22]. The weather stations that were used to represent each crop district are shown in table 5.3.

Table 5.3: List of Representative Weather Stations for Various Crop Districts

Crop District	Weather Station
1a	Estevan
1b	Moosomin
2	Indian Head
3	Swift Current
4	Maple Creek
5	Kelliher
6	Outlook
7a	Kindersley
7b	Scott
8	Melfort
9	Prince Albert

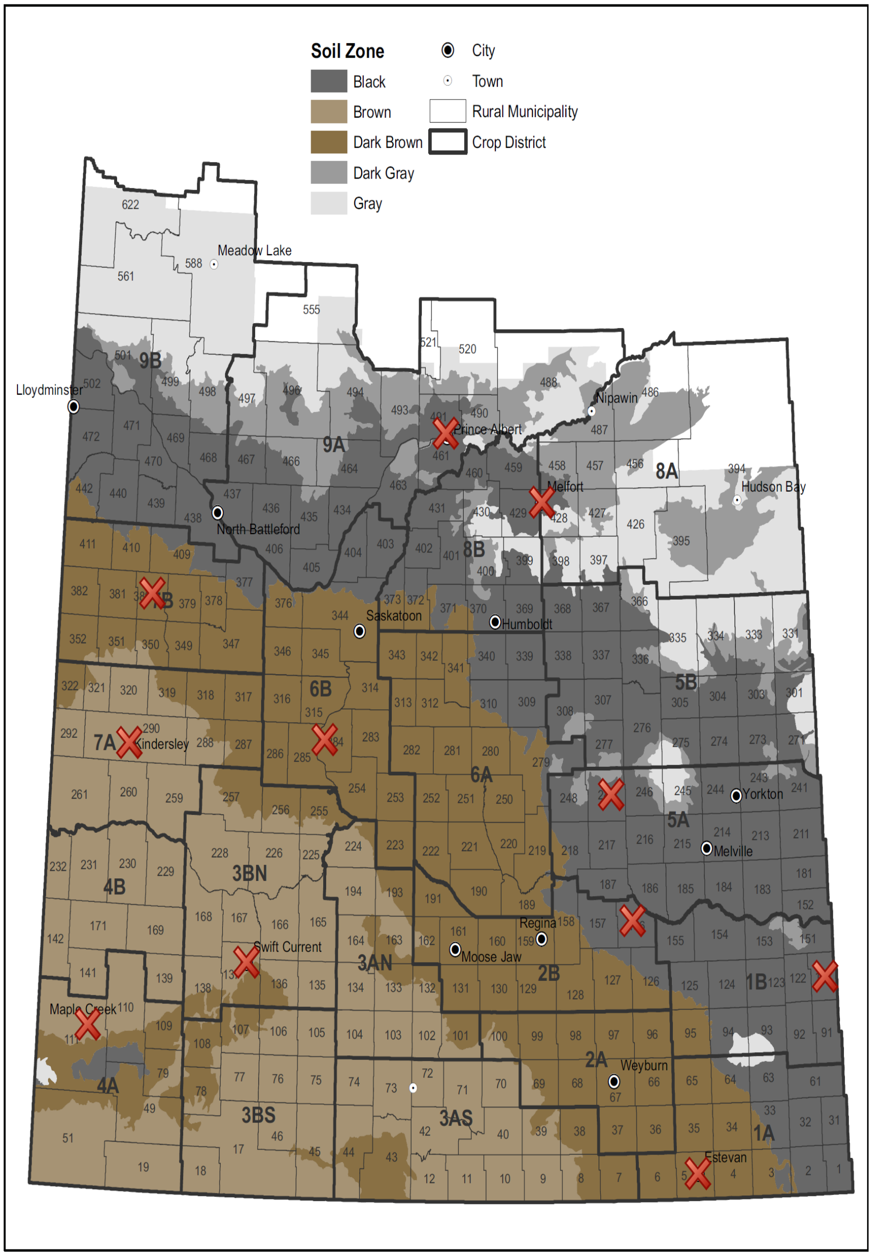
Supply response studies dictate that area of crop planted per year depends on past or historical indicators, including climatic variables. Therefore, the summer (July) and fall (October) climatic variables for all linear, nonlinear and interaction terms were lagged by one year. However, including this measure of climate has not been used in previous studies using choice models and it also resulted in less

[20] Precipitation as defined by Environment Canada is: any and all forms of water, liquid or solid, that falls from clouds and reaches the ground. This includes drizzle, freezing drizzle, freezing rain, hail, ice crystals, ice pellets, rain, snow, snow pellets, and snow grains (Environment Canada, 2006).

[21] Olympic averages omit the highest and lowest value and average the remaining. In historical weather data this was done by using the surrounding four years (top and bottom) of the missing value.

[22] There was also an issue with some recent year's monthly data missing; this issue was addressed by summing the available daily data at the same station.

statistically significant coefficients in each estimated equation. Therefore, following choice theory literature, the climatic variables were represented using current climate for each season.



Source: Government of Saskatchewan (2012)

Figure 5.1: Southern Saskatchewan Soil Zones with an Overlay of Crop Districts and Corresponding Weather Stations[23]

[23] Marked by red "x".

ii) Economic Variables

The economic set of variables hypothesized to affect crop choice decisions included those that affect farm level returns. Two sub-sets of variables were included: (1), those affecting demand for feed, and (2), those affecting profitability of a crop in a given crop year. These are further described below.

On-Farm Hog and Cattle Inventory

Demand for forages and feed is a strong incentive for a farmer to plant more forage crops. One of the major determinants for forage and feed demand is the on-farm inventory of hogs and cattle. This variable included the total number of animals on farms as of July 1st of each year. This is of importance because many farms produce grain to feed animals on farm.

There were some issues with missing pig inventory data in crop district 1a for the years 1992 to 2010. This information was replaced by subtracting the other crop districts values from the total pig inventory in Saskatchewan for those years. Also, inventories were only collected for consecutive years beginning in 1996 for both pigs and cattle. From 1981 to 1996 inventory by CD was only available by census year, although the Government of Saskatchewan collected this data yearly for the province as a whole. The years in between census available data were extrapolated by using the percentage of pigs and cattle in each crop district out of the total in Saskatchewan.

Price Variables

The specified model included prices of the commodities in the estimation. Due to the large time frame covered, most prices were represented by the average farm price for the year (or first transaction price[24]). This farm price represents the final market price that farmers receive less deductions, such as

[24] Commodities are priced at point of first transaction, where the fees deducted before a producer is paid are excluded, but bonuses and premiums that can be attributed to specific commodities are included (Statistics Canada, 2013d).

freight rates, elevator rates, etc. It also represents both the initial and final payments for CWB commodities. Because the crops are grouped together, the yearly average of each crop were summed and averaged to represent the entire group. For example, the feed group was represented by the average farm price of winter wheat, rye, barley[25] and oats. A common measure of price that has been used in various studies is a simple one or two period lag or moving average of past prices (Amiraslany, 2010; Bailey & Womack, 1985; Krakar & Paddock, 1985)[26]. Therefore, a three year moving average of past prices was calculated to best represent the expected price for these crop groups.

Two major issues in measuring price variables were encountered in this study: (i) availability of provincial average prices; and (ii) missing prices. For the first issue, secondary data sources only report average farm level price for the province of Saskatchewan as a whole. In reality, however, it should be noted that prices received by farmers vary from location to location due to differences in transportation costs, freight costs, elevator fees, etc. Ideally these data would be the best to use, but availability of such detailed information is limited and therefore, not included in this study. The second issue pertained to farm prices for mustard seed, canary seed, lentils, chickpeas and dry peas. Because production of some of these crops is relatively new, accurate historical price information on them is not available. In some cases is it related to the limited scale of production, which causes confidentially issues at a CD level. In these cases, if there were only a few years of data missing, these values were extrapolated; otherwise these values were left blank and averaged over the remaining crop prices in the specified crop group (for more information about addressing missing price issues refer to Appendix A).

In the specialty oilseed group, flax prices were available at the farm level but canary seed prices were available at first transaction and only for the years 1987 to 2010. The pulse group included prices

[25] Note that both malting barley and feed barley are combined to represent total barley price.
[26] There are various other, more complex, measures of that have been used to represent price such as weighted averages and geometric weighted averages, however, this focus is more common when modeling the impact of expected prices and risk on area allocation.

for lentils and peas at the first transaction only. These were also only available from the years 1987 to 2010. Prices from 1981 to 1986 were obtained for dry peas through the Government of Manitoba. Again these were only available at the first transaction. As chickpeas have not been grown for a significant period in Saskatchewan, the pulse group was represented by the more dominant crops of dry peas and lentils. Forage prices were missing for the years 2005 to 2010. As a substitute, these prices were obtained from Manitoba Agriculture Food and Rural Initiatives. Mustard seed prices were also not available for a majority of years in the study period; however recent past trends show that prices of the specialty oilseeds tend to move in the same direction with the exception of some peaks (refer to Appendix A for further discussion on the handling of missing data).

iii) Socio-economic (Policy) Variables

The next set of variables represents important policy changes that have occurred over the study period. These policy changes were included through binary variables. The first binary variable was related to change in rail transportation policy that occurred in 1983. This was the change in grain freight rate by producers for export grains. This change in policy was significant because it changed the prices that farmers received for exports of major commodities, specifically the prices for grains such as those marketed through the CWB (i.e. durum, spring wheat, barley).

Another policy change included in the model was the change in the status of oats marketing. In 1989, oats were removed from the CWB. The removal of oats from the CWB marketing had a large impact on the manner by which oats were marketed and therefore on the area devoted to this crop. A third policy change variable was related to the Permanent Cover Program (PCP). As a result of the program implementation it is likely that the choice to seed tame hay would have been affected and thus, this variable will represent those years.

iv) Geographic (Spatial) Variables

The spatial variables that were included in the model were the soil zones representing land characteristics in various CD's. There heterogeneity with respect to land productivity is captured through the binary variables. Since there are three major soil zones in Saskatchewan – brown, dark brown and black (as shown in figure 5.1), two binary variables were selected for the model. These were the brown and dark brown soil zones.

5.5 Model Specification

Equation 5.1 presented above was now extended to show full specification of the model. The left hand side variable represented the share of area devoted to a group of crops (as noted in Table 5.2) in a specific CD (as noted in table 5.1). The right hand side of the equation included all the explanatory variables under the four categories as explained in section 5.4. The final model is shown in equation 5.2.

$$Y_{it} = \beta_0 + \beta_1 JT_t + \beta_2 AT_t + \beta_3 JuT_t + \beta_4 OT_t + \beta_5 JP_t + \beta_6 AP_t + \beta_7 JuP_t + \beta_8 OP_t + \beta_9 JT_t^2 + \beta_{10} AT_t^2 + \beta_{11} JuT_t^2 + \beta_{12} OT_t^2 + \beta_{13} JP_t^2 + \beta_{14} AP_t^2 + \beta_{15} JuP_t^2 + \beta_{16} OT_t^2 + \beta_{17} JT_t{*}JP_t + \beta_{18} AT_t{*}AP_t + \beta_{19} JuT_t{*}JuP_t + \beta_{20} OT_t{*}OP_t + \beta_{21} I_{beef} + \beta_{22} I_{pig} + \beta_{23} D_{DBSZ} + \beta_{24} D_{BRSZ} + \beta_{25} D_{CN} + \beta_{26} D_{oats} + \beta_{27} D_{PCP} + B_{28} P_{WG} + \beta_{29} P_{CG} + \beta_{30} P_{PG} + \beta_{31} P_{FG} + \beta_{32} P_{SG} + \beta_{33} P_{FO} + e_t \quad \ldots \ldots (5.2)$$

Where i = 1,2,…,7 (Crop groups)

Where t = 1981, 1982,…, 2010

The non-linear terms are represented by the superscript '2' and the interaction terms are represented by the asterisk (*). The variable definitions can be found in Table 5.4.

Table 5.4: Variable Definition[27], Measurement and Source

Variable		Definition	Unit of Measure	Source*
Dependent Var.				
	Wheat	n/a	% of total share by CD	Stats Can, SK Min of Ag, U of S Lib
	Canola	n/a	% of total share by CD	Stats Can, SK Min of Ag, U of S Lib
	Pulses	n/a	% of total share by CD	Stats Can, SK Min of Ag, U of S Lib
	Feed	n/a	% of total share by CD	Stats Can, SK Min of Ag, U of S Lib
	Specialty	n/a	% of total share by CD	Stats Can, SK Min of Ag, U of S Lib
	Forages	n/a	% of total share by CD	Stats Can, SK Min of Ag, U of S Lib
	Summerfallow	n/a	% of total share by CD	Stats Can, SK Min of Ag, U of S Lib
Independent Var.				
Climatic	JT	January temperature	°C	Env Can
	AT	April temperature	°C	Env Can
	JuT	July temperature	°C	Env Can
	OT	October temperature	°C	Env Can
	JP	January precipitation	mm	Env Can
	AP	April precipitation	mm	Env Can
	JuP	July precipitation	mm	Env Can
	OP	October precipitation	mm	Env Can
Economic	I_{beef}	On farm beef inventory	# of head, total cattle and calves	Stats Can, SK Min of Ag, U of S Lib
	I_{pig}	On farm pig inventory	# of head,market & bred pigs, gilts and boars	Stats Can, SK Min of Ag, U of S Lib
	P_{WG}	Moving average price of wheat group	$CAD/tonne	Stats Can, SK Min of Ag
	P_{CG}	Moving average price of canola group	$CAD/tonne	Stats Can, SK Min of Ag
	P_{PG}	Moving average price of pulse group	$CAD/tonne	Stats Can, SK Min of Ag & MAFRI
	P_{FG}	Moving average price of feed group	$CAD/tonne	Stats Can, SK Min of Ag
	P_{SG}	Moving average price of specialty group	$CAD/tonne	Stats Can, SK Min of Ag
	P_{FO}	Moving average price of forages group	$CAD/tonne	Stats Can, SK Min of Ag, MAFRI
Policy	D_{CN}	Crows Nest Past Agreement	1 in years agreement was in place (1980-1983)	n/a
			0 otherwise	
	D_{oats}	Oats off CWB marketing	1 in years oats were marketed by CWB (1980-1989)	n/a
			0 otherwise	
	D_{PCP}	Permant Cover Program	1 in years where the PCP was active (1989-1992)	n/a
			0 otherwise	
Geographic	D_{DBSZ}	Dark brown soil zone	1 if crop district is in the DBSZ	n/a
(Spatial)			0 otherwise	
	D_{BRSZ}	Brown soil zone	1 if crop district is in the BRSZ	n/a
			0 otherwise	

*Stats Can: Statistics Canada; SK Min of Ag: Saskatchewan Ministry of Agriculture; MAFRI: Manitoba Agriculture, Food & Rural Initiatives; Env Can: Environment Canada; U of S Lib:University of Saskatchewan Data Library - Agriculture Census 1981, 1986, 1991,1996, 2001, 2006

[27] Further variable definition can be found in Appendix B.

5.6 Data Sources and Descriptive Statistics

The unit of measure and data sources for the dependent and independent variables used in estimation are shown in Table 5.4. The years covered are from 1981 to 2010. With 11 CDs and 30 years of data, the pooled sample resulting in a panel data set of 330 observations.

Table 5.5 shows selected statistics for the dependent and independent variables included in the model. These included mean, standard deviation, as well as the range (minimum and maximum value) for each variable. The binary variables are not reported since their mean values have little interpretation. Their values vary between a minimum and 0 and a maximum of 1.

The means for the dependent variables are the average share of the crop group to total area over the 30 year period. Wheat and forages crop groups have the most noteworthy means representing 60 percent of the total area in Saskatchewan. The canola and feed group are the next two crop groups that account the most area over the time period at about 35 percent. The other crop groups account for the remaining five percent of total area. It is also significant to note that the maximum share of wheat was as high as 74 percent of total area and forages for nearly 50 percent.

The climatic variables show a diverse range of weather patterns that have been experienced over the 30 year period in Saskatchewan. January temperature averaged minus 13°C and has the largest standard deviation -- temperatures drop close to negative 30°C, and rise up to 6°C. April is generally a cool month with an average temperature of 5°C, however the minimum and maximum value indicate temperatures below zero and above 20°C are possible. October has similar patterns, also being a cooler month (average mean temperature of 4°C) with temperature as low as minus 21°C and a high close to 10°C.

Table 5.5: Descriptive Statistics for Dependent and Independent Variables

	Variable	Mean	Standard Deviation	Min	Max	No. of Obs.
Dependent Variables	Wheat	0.3623	0.0996	0.1240	0.7387	330
	Canola	0.1048	0.0911	0.0001	0.3929	330
	Pulses	0.0488	0.0529	0.0001	0.2750	330
	Feed	0.1277	0.0593	0.0312	0.2969	330
	Specialty	0.0387	0.0303	0.0005	0.1403	330
	Forages	0.2476	0.1139	0.0439	0.4879	330
	Summerfallow	0.0701	0.0421	0.0066	0.2196	330
Independent Variables	JT	-13.3994	5.8411	-29.70	6.60	330
	AT	4.8526	3.3013	-4.70	20.10	330
Continuous only	JuT	18.3530	1.6485	14.20	24.30	330
	OT	3.8973	3.9278	-21.80	9.60	330
	JP	16.9079	10.3546	0	75.40	330
	AP	26.4555	20.3493	0	140.60	330
	JuP	64.3386	39.6363	2.80	205.80	330
	OP	23.6380	17.8654	0	103.70	330
	JT^2	213.5586	149.2950	0.25	882.09	330
	AT^2	34.4130	55.5355	0	404	330
	JuT^2	30.5701	47.9031	0	475	330
	OT^2	339.5432	61.3545	201.64	590.49	330
	JP^2	392.7688	526.9711	0	5685	330
	AP^2	1112.7300	1916.5020	0	19768	330
	JuP^2	5705.7340	6769.7360	7.84	42353.64	330
	OP^2	876.9601	1395.7980	0	10754	330
	JT*JP	-235.0466	198.0393	-1093.30	244.53	330
	AT*AP	142.0304	213.5920	-84.60	1949.50	330
	JuT*JuP	1157.2350	698.1321	68.04	4074.84	330
	OT*OP	93.7040	109.9637	-391.92	535.60	330
	I_{beef}	243152	164864	13629	755580	330
	I_{pig}	79333	80346	0	552695	330
	P_{WG}	171.3888	35.9793	115.50	268.50	330
	P_{CG}	309.5991	50.1955	240.00	439.33	330
	P_{PG}	258.8549	41.6320	202.04	417.15	330
	P_{FG}	118.8932	22.8015	87.42	179.67	330
	P_{SG}	306.8560	71.2194	196.78	470.42	330
	P_{FO}	73.5389	10.9946	54.33	99.67	330

The precipitation values highlight how the province suffers from low, unreliable rainfall. The month with the most rainfall is July with an average of 64 mm. April has an average precipitation of 26 mm, however both April and July experience low values for their minimums at 2 mm and zero respectively. It is also significant to note the high standard deviations that accompany these variables. This showcases the extreme variability in precipitation that exists in these months. January and October precipitation is the lowest out of all four seasons. Furthermore, in January precipitation is mostly in the form of snow, while in October it is a combination of both rainfall and snowfall.

It is also important to note that the non-linear terms (indicated by the superscript 2) represent the square of the linear temperature and precipitation values for each month. The interaction terms (represented by the asterisk) represent each months precipitation multiplied by that same month's temperature. Therefore both these values have high means and maximums.

Between beef and pig inventory, beef numbers account for the most on farm inventory. However, there is a large standard deviation for the beef inventory and a large gap between the minimum and maximum values. This is likely caused by the BSE crisis where there was a large drop in cattle inventory across Saskatchewan. Pig inventory also has a large standard deviation and a large gap between maximum and minimum values. This could be attributed to the financial hardships the hog market has experienced in recent years as producers try and reduce the size of their pig herd.

The price variables show the volatility that accompanies commodity markets even though they are represented by three year moving averages. Canola, pulses and specialty crops have the highest mean farm price per tonne, and also have the highest maximum values, showing them to be cash crops as they command higher market prices. Feed, wheat and forage prices have the lowest mean farm price per tonne. Their standard deviations are also the lowest, which can be contributed to the federal and provincial support they receive as well as from the CWB marketing.

It is of consequence to note that the mean and standard deviation values are representative of all CDs combined, while the minimum and maximum represent the lowest and highest value by CD. That is the reason for some minimum values being as low as zero and maximums being high. Also, for simplicity only the linear variables for temperature were discussed.

5.7 Estimation Procedure

Estimation of the model was done using the statistical software STATA. The “fmlogit” command in STATA fits a fractional logit model to a given set of data using quasi maximum likelihood method. This method is ideal for large, multivariate data sets. Six equations were estimated with wheat serving as the base or comparison equation. Therefore all results need to be interpreted as the choice between wheat and an alternative crop group. The choice of wheat as the comparison was made in light of the fact that it is the most significant crop group in all CD’s of the province and has the longest historical record for data.

Post-estimation commands are also available in STATA, which include marginal effects[28] which are the best way to interpret the results of the fractional multinomial logit model[29]. Fixed or random effects estimation methods are not applicable because the dependent variable is limited within the range of zero and one, and considering fixed effects would remove time constant variables such as land characteristics (Yin et al., 2010). For this analysis, it was assumed that the independence of irrelevant alternatives (IIA) hypothesis holds in estimation.

Possible issues that could arise when estimating the model include multicollinearity and misspecification. Multicollinearity is likely to arise between the climate variables, notably the linear and

[28] Marginal effects are defined as the change in the predicted value of a dependent variable for a unit change in the explanatory variable, assuming that the effect does not change over that interval (i.e. time period), calculated at the mean (Stata, 2013).
[29] Full code including estimated values is presented in Appendix C.

non-linear representations because they are transformations of one another. It is also common when using consecutive months; however this problem is avoided by using the months representing each season, as was done in this study.

Correlation may also exist spatially among the climatic variables. This is likely to occur when using panel data because climate data from the chosen weather stations likely move the same way as nearby stations, therefore they may be spatially correlated. Multicollinearity can also exist among the price variables since commodity prices historically move together due to substitution effects. Misspecification may also arise. Although every effort was made to include all relevant variables in the model, on account of a paucity of comparable studies (as exemplified by the literature review), it is conceivable that some relevant variables may not have been included.

5.8 Simulation

After estimating the FMNL model, the results were used to run a simple simulation showing how future climate will impact acreage allocation decisions, holding other factors constant. The estimated projections of climate were obtained from Price et al. (2011)[30]. Due to the aggregation level for ecozones, the three Saskatchewan soil zones were well represented in this particular study. These values were transformed into the non-linear forms of the climate variables. Simulation results were compared with the base year of 2000 and each crop group was compared to the base commodity group of wheat.

For the simulation, soil zones were used in place of the Crop Districts for simplicity as described in section 5.2.2 of this chapter. Using crop districts as the spatial scale for the simulation would result in 33 scenarios with three projected years each. There would likely be little variation using this spatial scale and interpretation would be tedious and repetitive.

[30] Further detailed in Chapter 6, section 6.5.

The simulation was undertaken for the six crop groups using the three soil zones for regional comparisons. Recall the estimated equation as shown in 5.1. After estimation, all coefficients were determined as well as a fitted acreage value for all crop groups, save the base group wheat as follows:

$$\hat{Y}_{it} = \hat{\beta}_0 + \hat{\beta}_1 JT_t + \hat{\beta}_2 AT_t + \hat{\beta}_3 JuT_t + \hat{\beta}_4 OT_t + \hat{\beta}_5 JP_t + \hat{\beta}_6 AP_t + \hat{\beta}_7 JuP_t + \hat{\beta}_8 OP_t + \hat{\beta}_9 JT_t^2 + \hat{\beta}_{10} AT_t^2 + \hat{\beta}_{11} JuT_t^2 + \hat{\beta}_{12} OT_t^2 + \hat{\beta}_{13} JP_t^2 + \hat{\beta}_{14} AP_t^2 + \hat{\beta}_{15} JuP_t^2 + \hat{\beta}_{16} OT_t^2 + \hat{\beta}_{17} JT_t{*}JP_t + \hat{\beta}_{18} AT_t{*}AP_{t+1} + \hat{\beta}_{19} JuT_t{*}JuP_t + \hat{\beta}_{20} OT_t{*}OP_t + \hat{\beta}_{21} I_{beef} + \hat{\beta}_{22} I_{pig} + \hat{\beta}_{23} D_{DBSZ} + \hat{\beta}_{24} D_{BRSZ} + \hat{\beta}_{25} D_{CN} + \hat{\beta}_{26} D_{oats} + \hat{\beta}_{27} D_{PCP} + \hat{B}_{28} P_{WG} + \hat{\beta}_{29} P_{CG} + \hat{\beta}_{30} P_{PG} + \hat{\beta}_{31} P_{FG} + \hat{\beta}_{32} P_{SG} + \hat{\beta}_{33} P_{FO} \quad \text{(5.3)}$$

To simulate changes in the future (t+1) the new equation will be the following[31]:

$$\hat{Y}_{it} = \hat{\beta}_0 + \hat{\beta}_1 JT_{t+1} + \hat{\beta}_2 AT_{t+1} + \hat{\beta}_3 JuT_{t+1} + \hat{\beta}_4 OT_{t+1} + \hat{\beta}_5 JP_{t+1} + \hat{\beta}_6 AP_{t+1} + \hat{\beta}_7 JuP_{t+1} + \hat{\beta}_8 OP_{t+1} + \hat{\beta}_9 JT_{t+1}^2 + \hat{\beta}_{10} AT_{t+1}^2 + \hat{\beta}_{11} JuT_{t+1}^2 + \hat{\beta}_{12} OT_{t+1}^2 + \hat{\beta}_{13} JP_{t+1}^2 + \hat{\beta}_{14} AP_{t+1}^2 + \hat{\beta}_{15} JuP_{t+1}^2 + \hat{\beta}_{16} OT_{t+1}^2 + \hat{\beta}_{17} JT_{t+1}{*}JP_{t+1} + \hat{\beta}_{18} AT_{t+1}{*}AP_{t+1} + \hat{\beta}_{19} JuT_{t+1}{*}JuP_{t+1} + \hat{\beta}_{20} OT_{t+1}{*}OP_{t+1} + \hat{\beta}_{21} I_{beef} + \hat{\beta}_{22} I_{pig} + \hat{\beta}_{23} D_{DBSZ} + \hat{B}_{28} P_{WG} + \hat{\beta}_{29} P_{CG} + \hat{\beta}_{30} P_{PG} + \hat{\beta}_{31} P_{FG} + \hat{\beta}_{32} P_{SG} + \hat{\beta}_{33} P_{FO} \quad \text{(5.4)}$$

Note that only the climate variables are changing and the remaining variables are held constant at the base level. Therefore the new equation includes changes only for the climate variables:

$$\Delta Y = \hat{Y}_{it+1} - \hat{Y}_{it} = \hat{\beta}_0 + \hat{\beta}_1(JT_{t+1} - JT_t) + \hat{\beta}_2(AT_{t+1} - AT_t) + \hat{\beta}_3(JuT_{t+1} - JuT_t) + \hat{\beta}_4(OT_{t+1} - OT_t) + \hat{\beta}_5(JP_{t+1} - JP_t) + \hat{\beta}_6(AP_{t+1} - AP_t) + \hat{\beta}_7(JuP_{t+1} - JuP_t) + \hat{\beta}_8(OP_{t+1} - OP_t) + \hat{\beta}_9(JT_{t+1} - JT_t)^2 + \hat{\beta}_{10}(AT_{t+1} - AT_t)^2 + \hat{\beta}_{11}(JuT_{t+1} - JuT_t)^2 + \hat{\beta}_{12}(OT_{t+1} - OT_t)^2 + \hat{\beta}_{13}(JP_{t+1} - JP_t)^2 + \hat{\beta}_{14}(AP_{t+1} - AP_t)^2 + \hat{\beta}_{15}(JuP_{t+1} - JuP_t)^2 + \hat{\beta}_{16}(OT_{t+1} - OT_t)^2 + \hat{\beta}_{17}([JT_{t+1}{*}JP_{t+1}] - [JT_t{*}JP_t]) + \hat{\beta}_{18}([AT_{t+1}{*}AP_{t+1}] - [AT_t{*}AP_t]) + \hat{\beta}_{19}([JuT_{t+1}{*}JuP_{t+1}] - [JuT_t{*}JuP_t]) + \hat{\beta}_{20}([OT_{t+1}{*}OP_{t+1}] - [OT_t{*}OP_t]) + \hat{\beta}_{21} I_{beef} + \hat{\beta}_{22} I_{pig} + \hat{\beta}_{23} D_{DBSZ} + \hat{\beta}_{24} D_{BRSZ} + \hat{B}_{28} P_{WG} + \hat{\beta}_{29} P_{CG} + \hat{\beta}_{30} P_{PG} + \hat{\beta}_{31} P_{FG} + \hat{\beta}_{32} P_{SG} + \hat{\beta}_{33} P_{FO} \quad \text{(5.4)}$$[32]

Changing the climate variables is hypothesized to result in a change of the share of area seeded to each crop (ΔY_i) in the different soil zones. These results were used to compare the base equation to the simulated equations to estimate the impact of climate change on crop choices in Saskatchewan.

[31] Note that because of the base year being 2000, the three remaining binary variables will drop out of the equation.
[32] The remaining variables held constant at their mean.

5.9 Conclusion

In Chapter 4 the FMNL model was described in terms of its advantage for modelling decision making with multiple options, the important factors that influence these decisions, and the reasons for this model being the most appropriate model choice for this research question. This chapter described the variables that are of significance to Saskatchewan and to the specific research question. The data, its sources and its measurement were described in detail and the equation to be estimated was illustrated mathematically. The simulation to be carried out was described in detail with a technical representation as well. The software being used and estimation procedure was outlined, providing a link to the next chapter discussing the results of the estimated model and the simulation.

CHAPTER 6

MODEL & SIMULATION RESULTS

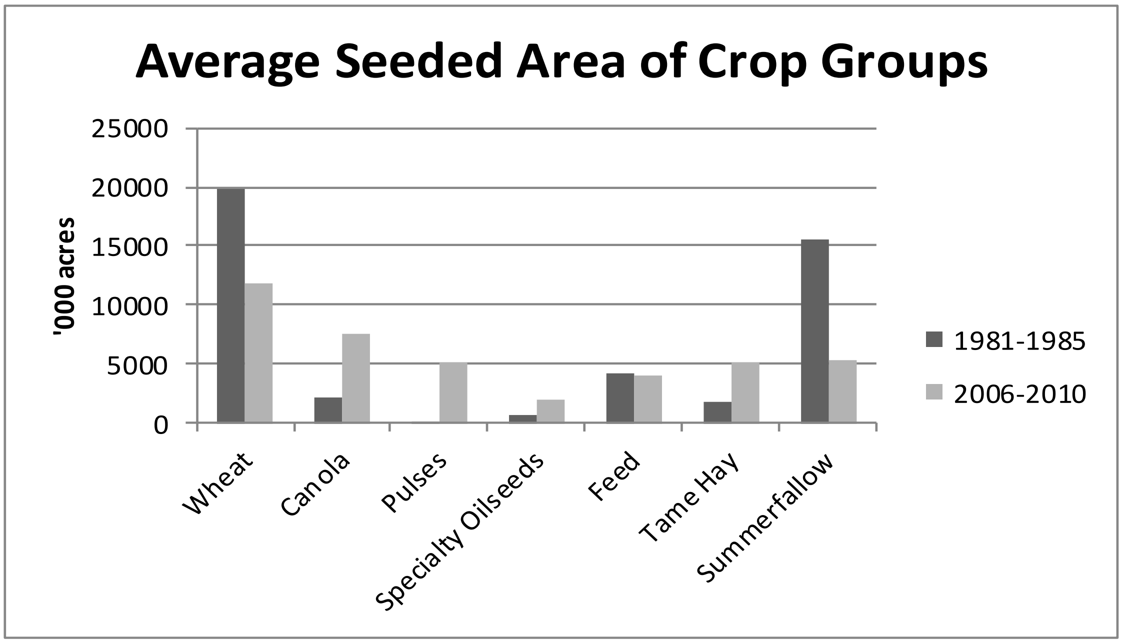
6.1 Introduction

The previous chapters outlined the study methodology for estimating a FMNL model detailing the selected variables included in estimation. This chapter's first focus is on the results of the FMNL model. Section 6.2 gives an introduction to the current selection of crops in Saskatchewan for the year 2000 by soil zone. Section 6.3 briefly discusses the estimated parameters of the binary variables before moving onto the estimated marginal effects. These are discussed in detail for all the continuous variables that were estimated in the model. Section 6.4 discusses in detail the results of the marginal effects of various variables and their implications on area allocation decisions. The simple simulation model is presented next in section 6.5, showing how area of the seven crop groups may change under future climate scenarios. This chapter will conclude with the final findings based on the estimated model and the simulation results.

6.2 Current Selection of Crops in Saskatchewan

Before presenting the results of estimated model, it useful to understand the current crop area allocation in the province. Since this thesis is a regional analysis of area allocation for various crops, current allocation of the total regional area was examined further. Figures 6.1 through 6.4 show the distribution of the crop groups by soil zone for the base year of 2000. Table 6.1 further details distribution of crop groups by soil zone for the base year.

Wheat is the dominant crop in the province during the base year (2000) as supported by evidence in Table 6.1 as well as the figures. Next to wheat, the pulse and summerfallow groups have higher shares in the brown and dark brown soil zones. Specialty oilseeds dominate in the black soil zone, while a smaller area is devoted to this in the brown and dark brown. Canola area is low in the brown soil zone (on account of climate suitability) but it is mostly contained to the dark brown and black soil zones. Forages have the most area in the black soil zone and the feed group has the most area in the dark brown.



Source: Saskatchewan Ministry of Agriculture (2013b), Statistics Canada (2013a) and University of Saskatchewan (n.d.b)

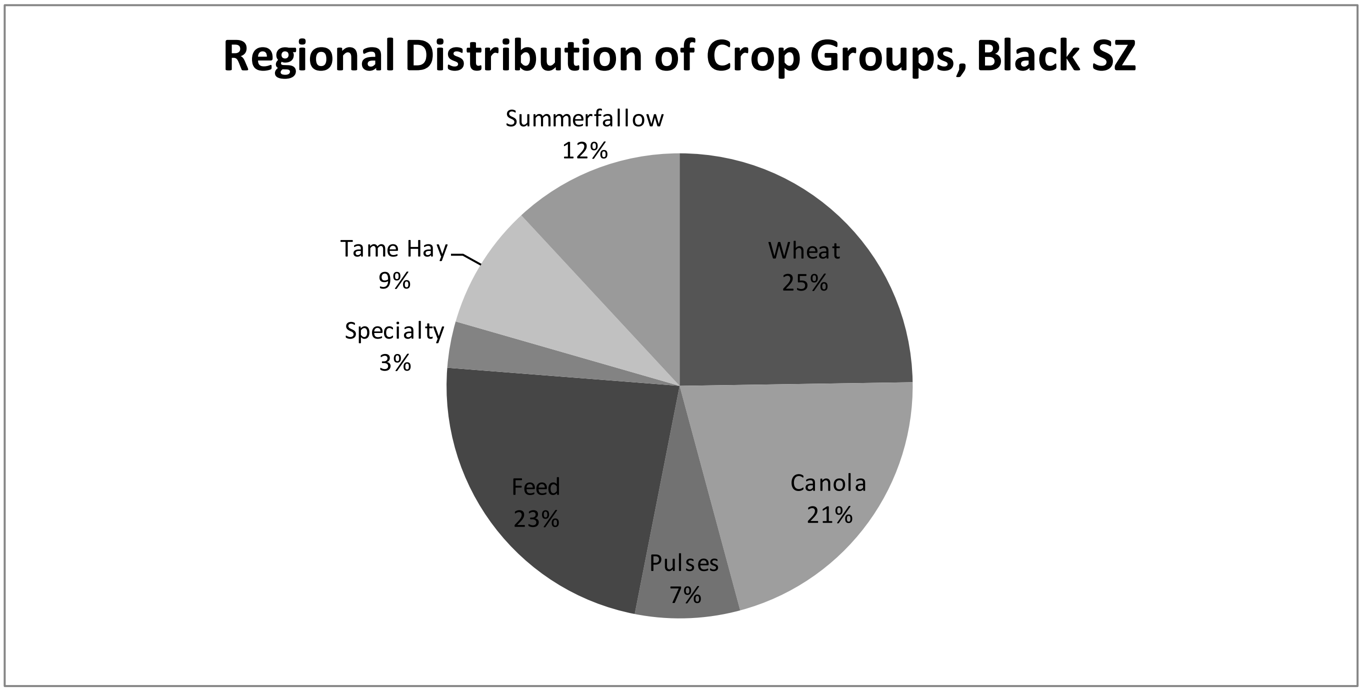
Figure 6.1: Average Seeded Area of Crop Groups, Saskatchewan

Table 6.1: Regional Distribution of Crop Groups by Soil Zone, Saskatchewan, year 2000[33]

	'000 acres			
CROP GROUP	**Brown SZ**	**Dark Brown SZ**	**Black SZ**	**TOTAL SK**
Wheat	4,825	5,090	4,142	14,057
Canola	392	1,948	3,525	5,865
Pulses	1,635	1,774	1,217	4,626
Specialty Oilseeds	1,002	2,253	3,875	7,130
Feed	476	870	540	1,886
Tame Hay	1,087	883	1,447	3,417
Summerfallow	3,825	2,438	1,990	8,253
TOTAL	13,242	15,256	16,736	45,234

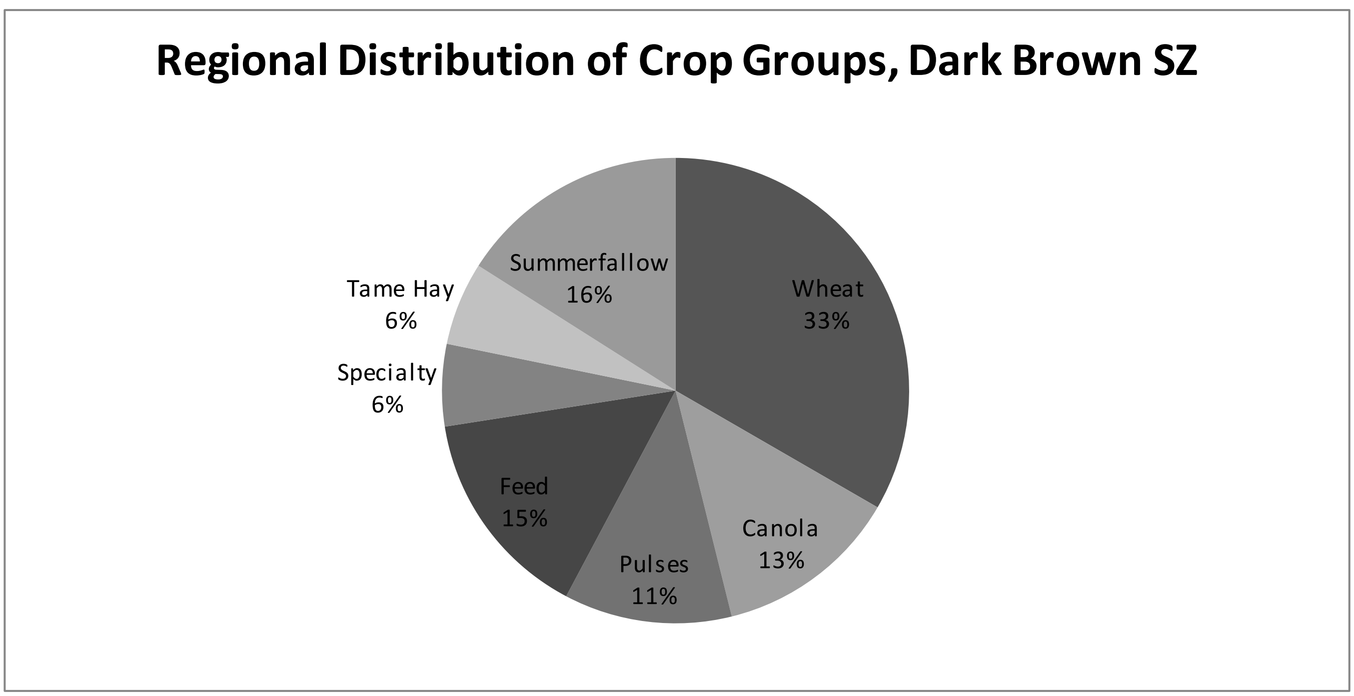
Source: Saskatchewan Ministry of Agriculture (2013b), Statistics Canada (2013a) and University of Saskatchewan (n.d.b)

[33] Note that these values represent the value for the dependent variable constructed for use in the model; such as combining crops and extrapolating missing values, therefore there will be a discrepancy between these values and values obtained from the Census of Agriculture.



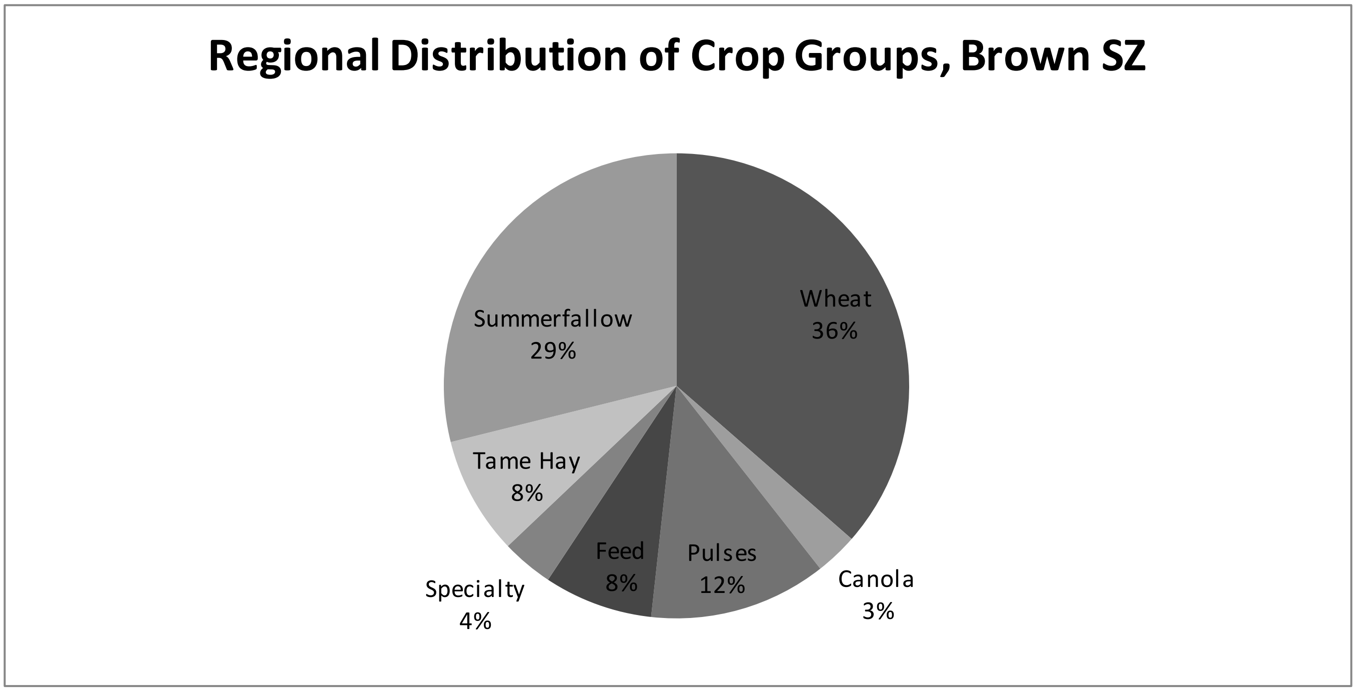
Source: Saskatchewan Ministry of Agriculture (2013b), Statistics Canada (2013a) and University of Saskatchewan (n.d.b)

Figure 6.2: Regional Distribution of Crop Groups by Black Soil Zone, Saskatchewan, year 2000



Source: Saskatchewan Ministry of Agriculture (2013b), Statistics Canada (2013a) and University of Saskatchewan (n.d.b)

Figure 6.3: Regional Distribution of Crop Groups by Dark Brown Soil Zone, Saskatchewan, year 2000



Source: Saskatchewan Ministry of Agriculture (2013b), Statistics Canada (2013a) and University of Saskatchewan (n.d.b)

Figure 6.4: Regional Distribution of Crop Groups by Brown Soil Zone, Saskatchewan, year 2000

6.3 Parameter Estimates

Parameter estimates from the FMNL model are presented and discussed in this section. Table 6.2 contains the marginal effects and their standard errors for the non-binary variables. No marginal effects were calculated for the binary variables; therefore, the only interpretation they have is whether they are significant in the FMNL model estimates. For simplicity and to conserve space, only the marginal effects are presented in this chapter[34]. Overall the model had a good fit with a Chi-square statistic of 15,229, much larger than any critical value at any significance level. Expectations of signs were based on economic logic, where applicable.

[34] Full STATA printouts including the two estimated FMNL models as well as the marginal effects for the chosen model and further discussion of specification testing can be found in Appendix C.

6.3.1 FMNL Estimates Overview

As expected, the binary variables representing land characteristics were significant in six of the estimated equations, with the exception of the brown soil zone, where this variable was not significant for the pulses commodity group. However, pulses only represent 12% of total area in this soil zone (refer to Figure 6.4). In all equations, with the exception of the Dark Brown soil zone in the pulses group and the Brown soil zone in the summerfallow, soil zones had a negative impact on the share of wheat over another commodity group. The high significance of the soil zones indicates the heterogeneity in acreage allocation decisions that are made in different soil zones.

The binary variable for the removal of oats from the CWB marketing was also significant in all the equations. In all groups except summerfallow the estimated coefficient was negative. The removal of the Crow's Nest Pass Agreement rates was only significant in pulses, specialty oilseeds and summerfallow decisions. Again the estimated coefficient was negative in all equations except the summerfallow equation. This is consistent with expectations as the removal of the Crow's Nest Pass rates increased transportation costs of specific commodities, thereby making them more expensive to ship for export. The PCP binary variable was significant in all but the summerfallow equation, again having a negative effect on wheat acreage. Overall it can be concluded that policy changes do have an impact on the area allocation decisions for various crop groups.

6.3.2 Marginal Effects

Table 6.2 shows the marginal effects (as defined in Chapter 5) of all the variables with their corresponding standard errors. Note that these estimates still maintain the sign of the estimated coefficients in the FMNL model.

Table 6.2: Marginal Effects of Continuous Explanatory Variables

	Wheat		Canola		Pulses		Specialty	
	coef.	s.e	coef.	s.e	coef.	s.e	coef.	s.e
JT	0.0007	0.0032	-0.0027	0.0018	0.0009	0.0007	-0.0004	0.0011
AT	0.0035	0.0039	-0.0055***	0.0019	-0.0021**	0.0009	-0.0010	0.0012
JuT	-0.0180	0.0384	0.0189	0.0258	-0.0097	0.0084	0.0098	0.0203
OT	-0.0045*	0.0024	0.0026**	0.0011	0.0001	0.0006	-0.0005	0.0012
JP	-0.0002	0.0015	-0.0003	0.0011	-0.0004	0.0003	0.0007	0.0007
AP	0.0001	0.0005	-0.0001	0.0002	-0.0002*	0.0001	0.0002	0.0002
JuP	-0.0019*	0.0010	0.0005	0.0008	-0.0002	0.0004	-0.0007	0.0005
OP	-0.0008	0.0008	0.0006	0.0004	0.0001	0.0002	0.0003	0.0003
JT^2	0.0000	0.0001	-0.0001	0.0001	0.0000	0.0000	0.0000	0.0000
AT^2	-0.0002	0.0003	0.00041***	0.0001	0.000094*	0.0001	0.0000	0.0001
JuT^2	0.0003	0.0010	-0.0006	0.0007	0.0002	0.0002	-0.0003	0.0005
OT^2	0.0001	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000
JP^2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
AP^2	0.0000	0.0000	0.0000	0.0000	0.0000016*	0.0000	-0.0000033**	0.0000
JuP^2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
OP^2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
JT*JP	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
AT*AP	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
JuT*JuP	0.00011*	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
OT*OP	0.0001	0.0001	-0.00011***	0.0000	0.0000	0.0000	0.0000	0.0000
I_{beef}	0.0000	0.0000	0.0000	0.0000	0.000000015***	0.0000	-0.000000072***	0.0000
I_{pig}	-0.00000013***	0.0000	0.00000013***	0.0000	0.0000	0.0000	0.000000036**	0.0000
P_{WG}	0.0001	0.0007	-0.00056**	0.0004	0.00034**	0.0002	0.0000	0.0002
P_{CG}	-0.0001	0.0002	0.0001	0.0001	-0.00013***	0.0001	-0.00015*	0.0001
P_{PG}	-0.00064***	0.0002	0.00034***	0.0001	0.0003***	0.0000	0.0000	0.0001
P_{FG}	0.00038**	0.0002	-0.00045***	0.0001	-0.0002***	0.0000	0.0000	0.0001
P_{SG}	-0.0004	0.0011	0.0014**	0.0006	-0.0002	0.0003	0.0003	0.0004
P_{TH}	-0.0026	0.0008	0.0016***	0.0005	0.0015***	0.0002	0.00075***	0.0003

*denotes significance at 10%, ** denotes significance at 5%, *** denotes significance at 1%

Table 6.2 (cont'd): Marginal Effects of Continuous Explanatory Variables

	Feed		Tame Hay		Summerfallow	
	coef.	s.e	coef.	s.e	coef.	s.e
JT	-0.0012	0.0019	0.0021*	0.0012	0.0007	0.0032
AT	-0.0063***	0.0023	0.0013	0.0013	0.01***	0.0039
JuT	-0.0462	0.0251	-0.044***	0.0146	0.089**	0.0447
OT	-0.0022**	0.0018	0.0019**	0.0010	0.0026	0.0026
JP	0.0006	0.0009	0.0004	0.0005	-0.0007	0.0017
AP	0.0000	0.0003	0.0001	0.0002	0.0000	0.0005
JuP	0.0017**	0.0007	0.0000	0.0004	0.0006	0.0012
OP	-0.0003	0.0005	0.0005	0.0003	-0.0004	0.0008
JT^2	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001
AT^2	0.00044**	0.0002	0.0000	0.0001	-0.00065**	0.0003
JuT^2	0.0014**	0.0006	0.0013***	0.0004	-0.0022**	0.0011
OT^2	-0.0001	0.0001	0.0000	0.0000	0.0001	0.0001
JP^2	0.0000	0.0000	0.0000	0.0000	0.000032*	0.0000
AP^2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
JuP^2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
OP^2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
JT*JP	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001
AT*AP	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001
JuT*JuP	-0.000088**	0.0000	0.0000	0.0000	0.0000	0.0001
OT*OP	0.0000	0.0001	0.0000	0.0000	0.0001	0.0001
I_{beef}	0.000000047***	0.0000	0.00000008***	0.0000	-0.00000013***	0.0000
I_{pig}	0.00000019***	0.0000	0.0000	0.0000	-0.00000023***	0.0000
P_{WG}	0.00072*	0.0004	0.00065***	0.0003	-0.0013**	0.0007
P_{CG}	0.0001	0.0001	-0.00038***	0.0001	0.00049***	0.0002
P_{PG}	-0.00026**	0.0001	0.00019***	0.0001	0.0000	0.0002
P_{FG}	0.0000	0.0001	0.0000	0.0001	0.0004	0.0002
P_{SG}	-0.0013**	0.0006	0.0000	0.0003	0.0002	0.0010
P_{TH}	0.0015***	0.0004	0.00077***	0.0003	-0.0035***	0.0007

*denotes significance at 10%, ** denotes significance at 5%, *** denotes significance at 1%

Effect of Climatic Variables

The effect of climatic variables were significant in all the estimated equations, however the specialty group had only one significant climatic related variable. The signs of the significant linear temperature coefficients suggest that increased temperatures in the spring (April) lower the share of canola, pulses and feed groups and increase the share to summerfallow. The positive temperature coefficient for January in forages and for April in the summerfallow equations indicates that warmer temperatures in these months lead to increases in the share of these two crop groups. Although warm weather is beneficial to crops, cold winters help to kill off diseases and pests and cooler springs help to make sure they do not damage seedlings. Therefore, farmers' may be taking this into account when preparing crop rotation for the following year.

July temperature is significant in both forages and summerfallow equations; however they have opposite signs. Increased temperatures in July decreased the share of forages by 0.044% over the study period, holding all other variables constant. In contrast, rising July temperatures increase the share of summerfallow by 0.089%, holding all other variables constant. These differing signs suggest that these two choices compete between one another for area allocation. Hot summer months are also a disadvantage to crop development; this result could indicate that farmers are switching to summerfallow in response to increases in summer temperatures over the study period.

Wheat, canola, feed and forages have significant coefficients for October temperature. For canola and forages this coefficient is positive, suggesting that a warmer fall increases the share of canola or forages. Canola area increases by 0.0026%, holding all other variables constant; and share of tame hay increases by 0.0019%, holding all variables constant over the study period. In some instances, canola can be seeded in the fall and grown through the winter; warmer Octobers open up this opportunity. Currently this practice is not common, but represents a potentially viable option given the projected changes in climate. Warm fall weather also gives the opportunity to graze cattle longer in pasture or to do a fall cut of hay. Increased temperatures in October decrease the share of wheat and feed, again this suggests that farmers may be moving away from traditional crops such as those in the wheat and feed groups in response to warmers falls.

A significant non-linear temperature effect was observed for canola, pulses, feed, forages and summerfallow. The linear and non-linear temperature coefficients for April were positive for canola, pulses and feed (increasing their respective share by 0.0004%, 0.000094% and 0.0004%, respectively, holding all other variables constant). These results indicate the importance of temperature at the beginning of the growing season. Because Saskatchewan already experiences relatively cold springs, increased temperatures in April are beneficial to crop production, and the positive nonlinear coefficient suggests that there is no maximum to this value. This finding is consistent with other studies using this measure of climate in the U.S. and Canada (Reinsborough, 2003; Mendelsohn & Reinsborough, 2007).

July temperature's nonlinear effect was another significant variable in the choice of feed, forages and summerfallow. Both feed and forages groups had positive coefficients indicating that there is a minimum rather than a maximum temperature where the choice of these crops would be made. These results can be defended as this particular set of crop groups are often consumed on farm and therefore detrimental yields as a result of extreme heat may not be as large of an issue compared to the damage it can do to wheat yields, thus the economic value of the crop. Again, this could indicate that as summer temperatures begin to increase, farmers can switch to these crops as an adaptation response to climate change. The opposite is true for summerfallow. Share of summerfallow increases as July temperature increases, but only up to a certain point as given by the negative non-linear coefficient. Again, this is defensible since increased temperatures may lead to increased evapotranspiration rates and some summerfallow practices have the potential to exacerbate moisture loss in soil.

Precipitation does not have as many significant coefficients in the estimated equations. This is not as expected due to the fact that moisture is an already a limiting factor in Saskatchewan and previous studies have noted the significance of precipitation. April precipitation is only significant in the pulses equation and an increase of 1 mm of precipitation in this month decreases the share of pulses by 0.0002%, holding all other variables constant. July rainfall has a significant and positive effect on the choice of the feed group, a 1 mm increase in July precipitation increases the share of feed by 0.0017%, holding all other variables constant. Since the feed group included fall seeded crops, and as wet summer months have the ability to spread diseases and pest infestations, farmers could switch to these crops to avoid such adversities. It also guarantees that these crops are seeded into a period with adequate moisture. Similar results have been found by previous studies supporting the finding that timing of precipitation is a key factor in plant development, thus influencing crop choice (see Amiraslany, 2010; Reinsborough, 2003; Weber & Hauer, 2003).

A statistically significant nonlinear effect of precipitation measures was noted for pulses, specialty oilseeds and summerfallow. April precipitation had differing signs with a positive coefficient for pulses and negative for specialty oilseeds suggesting that these two groups compete for the same area. It also indicates that the share of a specialty oilseed decreases when April precipitation reaches a maximum level, while the opposite is true for pulses. Interesting to note is that both April precipitation measures are significant but with differing signs for the pulse group. This effect of April precipitation has also been found by Reinsborough (2003). It appears that dry, cooler springs increase the choice of a pulse crop.

The July interaction terms were significant in both wheat and feed; however they had differing signs. Increased temperatures and precipitation in this month decreased the share of wheat but increased the share of feed over the study period. Again, this is conceivable since hot, humid weather is detrimental to wheat yields, as it increases the spread of diseases and pests. The October interaction term was significant in the Canola equation; however it decreased the share of canola. It was hypothesized that warmer and wetter Octobers would be beneficial to the crop rotation as it increased the length of the growing season (as found by Reinsborough, 2003 and Weber & Hauer, 2003); therefore this could signal that farmers may be switching to different crops when trends result in weather being more suitable in the fall.

Effect of Beef and Pig Inventory Levels

As expected the beef and pig inventory variables had at least one significant variable in each estimated equation, whereas in the feed equation both of them were positive and significant. An increase in beef inventory would lead to a $(4.7 \times 10)^8$ % increase in the share of feed crops, holding other variables constant. Similarly, an increase in pig inventory would result in an increase in the share of a feed crop by $(1.9 \times 10)^7$ %, holding other variables constant. The specialty oilseeds group also had a significant effect on beef and pig inventory variables. This effect was positive for pig inventory, increasing the share of a specialty oilseed by $(3.6 \times 10)^8$, holding all other variables constant; but negative for beef inventory, decreasing the share of this group by $(7.2 \times 10)^8$ %, holding others constant. This difference could be explained by that fact that recent research has suggested flaxseed is beneficial to a swine diet (Ontario Ministry of Agriculture and Food, 2012). It is also more common to feed pigs differing rations than with cattle. Summerfallow also had both livestock inventories having a significant but negative effect on the choice to leave land to fallow. On livestock farms, summerfallow may not be practiced as stringently as on grain and oilseed farms. Therefore the choice to leave fields to fallow would not be greater than the choice to use fields for feed or forage, for example.

For the wheat and canola share, pig inventory was the only variable that was significant. A 1% increase in pig inventory would decrease the share of wheat by $(1.3 \times 10)^7$ % holding all other variables constant. Similarly, this variable would increase the share of canola by (1.3 x 10) %, holding other variables constant. The beef inventory variable was only significant for the pulses and forages equations, with a 1% increase in beef inventory increasing the share of pulses or forages each by (1.5 x 10)^{8} % and (8.0 x 10)^{8}, respectively (for each coefficient holding other variables constant). Intuitively this makes sense as dry peas can be used in feed mix for cattle and forages can be used as pasture land to graze cattle. However, these results are quite small as dry peas command a high market price and would likely be sold for cash. The minute result for forages is not as easily explained, as it should be an important crop group for on-farm inventories of cattle.

Effect of Price Variables

Prices play an important role in acreage allocation decisions given the high level of significance in the estimated marginal effects for all crop groups. This significance is most prominent for canola and pulses with five of the six price variables being significant in each group. Wheat, pulses, specialty oilseeds, feed and forages prices all affect the decision to grow canola. As the price of pulses increases by $1/tonne, the share of canola increases by 0.0014%, holding all other variables constant. This same result was observed for feed and forages prices, which is expected on economic grounds. An increase of $1/tonne for feed increases the share of canola by 0.00034%, holding other variables constant; and an increase by the same amount for forages increases share of canola by 0.0016%, holding other variables constant. This result however, is unexpected on economic grounds; although it could be explained by the fact that canola has commanded such a high price in recent years that it may have precedence over marginal crop groups such as the forages. As expected, an increase in the price of wheat reduces the share of canola by 0.00056%, holding other variables constant. Similarly, an increase in the price of specialty oilseeds decreases the share of canola by 0.00045%, holding other variables constant. Both wheat and specialty oilseed prices had signs that were expected on economic grounds.

As mentioned, wheat was marketed through the CWB during the time period estimated, with initial prices announced before spring seeding and payments being virtually guaranteed. Therefore an increase in the price of wheat would negatively affect the share of any other crop that is sold on the open market where there is no guarantee of a high price. An increase in the price of other oilseeds (specialty) negatively affects the share of canola as expected, as this crop group is another viable crop rotation tool.

The share of the pulse group was influenced by the price of wheat, canola, pulses, specialty oilseeds and forages. Of these five prices, three of them increase the share of pulses – wheat, pulses and forages. As expected, an increase in the price of pulses by $1/tonne increases the share of pulses by 0.0003%, holding other variables constant. An increase in the price of wheat and forages also increases the share of the pulse group by 0.00034% and 0.0015% respectively (each holding other variables constant). Contrarily, and increase in canola and specialty oilseed prices decreases the share of pulses. A $1/tonne increase in price of canola decreases share of pulses by 0.00013%, holding other variables constant. Similarly, an increase in specialty oilseed prices decreases share of pulses by 0.0002%, holding other variables constant.

Feed and forages groups were the next crop group with the most influence of prices with four of six price variables being statistically significant. Wheat price positively affected the share of both these crop groups, with a $1/tonne increase in the price of wheat increasing the share of wheat or forages. An increase in the price of wheat increased the share of feed by 0.00072%, holding other variables constant. An increase in the price of forages increases the share of feed by 0.0015%, holding other variables constant. Forages had the same effect on both crop groups, with an increase in the price of forages increasing the share of feed or forages. An increase in the price for pulses and feed both decrease the share of a feed crop. As the price of pulses increases by $1/tonne, the share of feed decreases by 0.00026%, holding other variables constant. Similarly, as feed price increases, the share of feed deceases by 0.0013%, holding other variables constant. This finding is not as expected as an increase in own price would make the crop more desirable. However, because feed crops are used and managed differently[35] than the other crop groups, prices could be less influential on the feed crop choice.

The wheat, specialty oilseeds and summerfallow groups had the least amount of significant price variables. For the choice of area allocated to wheat, pulses and specialty oilseed the model revealed that oilseed prices were significant. A $1/tonne increase in the price of pulses decreases the share of wheat by 0.00064%, holding other variables constant. Alternatively, an increase in the price of specialty oilseeds increases the share of wheat by 0.00038%, holding other variables constant. The sign on prices of pulses was as expected; however the sign on specialty oilseed prices was not as expected.

The choice of a specialty oilseed was influenced by the price of canola and forages with an $1/tonne increase in the price of canola decreasing the share of specialty oilseeds by 0.00015%, holding other variables constant; and an increase in the price of forages increasing the share of canola by 0.00075%, holding other variables constant. Again, the sign on canola price was as expected since this is a cash crop and offers a high price in the open market. Share of summerfallow was negatively influenced by the price of wheat and forages as expected. As the price of wheat increases by $1/tonne, the share of summerfallow decreases by 0.0013%, holding other variables constant. Similarly, as the price of forages increase, the share of summerfallow decreases by 0.0035%, holding other variables constant. However, as canola price increases the share of summerfallow increases, which is not as expected.

[35] They are consumed on farm, can be sold privately, and there are not strict grading guidelines for protein content, weight, etc.

6.4 Discussion of Results

Overall, prices play a significant role in allocating area to the specified crop groups. However, the signs on some of the price coefficients were not as expected. For example, an increase in the price of wheat and pulses increases the share of forages. Also, in the summerfallow equation, an increase in canola prices increases the share of summerfallow. Another unexpected result with prices is that only wheat, pulses, feed and forages had significant coefficients for their own prices. This effect is positive for wheat, pulses and forages, increasing the share of each; however it was negative for feed. Overall, the prices that had the biggest effect were wheat, canola, pulses and forages. As mentioned, canola and pulses command high market prices. However the price of wheat was guaranteed over the study period. The unexpected signs for wheat, canola and pulse prices in some equations could be explained by this fact. Pulses also require special seeding equipment and in some cases, more stringent management practices. Forages on the other hand are produced on marginal land, which could explain why prices of forages is significant but positive in all equations but its own.

Climate appears to affect some crop groups more than others. For example, the specialty oilseeds crop group only has one significant climate variable. Wheat was the next group with a smaller number of climatic variables being significant. July precipitation and interaction terms were contradictory in the choice of wheat; as July rainfall increases the share of wheat declines but a combination of an increase in temperature and precipitation increases the share of wheat. This result is not as expected due to the threat of increased disease and pests spreading under these favourable conditions. All interactions terms with the exception of October, were expected to have a negative sign. The only October interaction term that was significant was negative, however the interaction term for July in the wheat and feed equation suggest that increased precipitation and temperature in these months result in these two crop groups competing for area.

Climate has the most impact on the choice of canola, pulses, feed, forages and summerfallow groups. Cool temperatures in spring are preferred for nearly all the crop groups except summerfallow. One of the most interesting results in the climate variables is in the summerfallow equation. Although summerfallow area has been on a steady decline, as temperatures increase in the spring and summer, the share of summerfallow may increase as well. Again, the results for April linear and nonlinear temperatures have been found by others (Reinsborough, 2003; Mendelsohn & Reinsborough, 2007), solidifying the finding that nonlinear climate effects play an important role in plant development, as well as the choice of which crops to grow.

One of the major conclusions from the results of the marginal effects is that climate seems to play an important role for the crops that are not sold through the CWB. The same results can be concluded for prices as well. The exception to both of these is for specialty oilseeds, where climate does not seem to have as much of an effect and prices affect it minimally. Specialty oilseeds make up the least amount of area over the 30 year time period; however it appears that if prices are favourable, they may be used in the crop rotation instead of canola. Wheat remains an important choice and this could be contributed to the CWB and the risk that the monopsony absorbed for farmers and its role in the crop rotation. It may also be explained by the fact that most farmers have good experience with this crop. Figure 6.1 shows how average seeded acreage of all the crop groups has changed from the 1981 to 1985 period and to 2006 to 2010. Seeded area has declined for wheat and increased for canola, pulses and specialty. The area allocated to the feed crops has remained relatively constant, while forages area has increased and summerfallow has declined. Wheat still makes up a significantly larger area than any of the other crop groups.

6.5 Simulation Results

As discussed in Chapter 5, the simulation was carried out using expected climate change data for the future from Price et al. (2011). The spatial scale used in the study split the prairies into two ecoregions: the semi-arid and the sub-humid. These two distinct ecoregions line up well with the soil zone profile of Saskatchewan, with the sub-humid region lying mostly across the black soil zone and the semi-arid on the southern brown and dark brown soil zone. Figures 6.2 through 6.4 show the distribution of the crop groups by soil zone for the base year of 2000. Table 6.2 further details distribution of crop groups by soil zone for the base year.

The projected climate change estimates pooled and averaged four well known third generation coupled global climate models (GCM), producing a set of twelve climate scenarios. These scenarios used simulated monthly means for 1961-1990 as the base for comparison and estimated projected changes for three 30 year periods: 2010-2039, 2040-2069 and 2070-2099. These estimates were further broken down into three scenarios: A2 the pessimistic scenario, A1B the medium scenario and B1 the optimistic scenario. Each scenario was developed using the IPCC global climate change projections for change in temperature and precipitation (refer to Chapter 3, Table 3.1 for the detailed descriptions of each scenario). The pessimistic scenario begins with a smaller change in temperature than the other two scenarios, but in the final projection period experiences the largest temperature increases. It is also the only scenario that projects a decline in precipitation from the base years; however, precipitation expectations have large variations between projected time periods. In general, the medium scenario has the least amount of variation between the projected three time periods for both temperature and precipitation. The optimistic scenario has less extreme warming than the other scenarios and both precipitation and temperature do not drastically change from one time period to another. The estimated changes in climate for the three scenarios for both ecoregions are presented in Table 6.3 and 6.4.[36]

Table 6.3: Climate Change Projections for Prairies Sub-humid (Black Soil Zone)

CLIMATE VAR	SCENARIO A2 'PESSIMISTIC'				SCENARIO A1B 'MEDIUM'				SCENARIO B1 'OPTIMISTIC'			
Mean daily min	**Spring**	**Summer**	**Fall**	**Winter**	**Spring**	**Summer**	**Fall**	**Winter**	**Spring**	**Summer**	**Fall**	**Winter**
2010-2039	0.64	1.04	1.11	1.7	1.1	1.29	0.86	2.07	0.74	0.97	1.02	1.36
2040-2069	2.2	2.62	2.41	3.94	2.3	2.77	2.42	4.09	1.31	1.82	1.85	2.9
2070-2099	3.9	4.51	3.97	6	0.05	3.66	3.5	5.34	2.03	2.47	2.49	3.71
Mean daily max												
2010-2039	0.52	1.06	0.95	1.1	1.03	1.34	0.85	1.45	0.72	0.88	0.97	0.82
2040-2069	2.01	2.68	2.39	2.7	2.04	2.82	2.32	2.75	1.12	1.76	1.8	1.99
2070-2099	3.36	4.68	3.77	4.24	2.77	3.77	3.54	3.8	1.88	2.55	2.6	2.59
Mean daily												
2010-2039	1.16	2.1	2.06	2.8	2.13	2.63	1.71	3.52	1.46	1.85	1.99	2.18
2040-2069	4.21	5.3	4.8	6.64	4.34	5.59	4.74	6.84	2.43	3.58	3.65	4.89
2070-2099	7.26	9.19	7.74	10.24	2.82	7.43	7.04	9.14	3.91	5.02	5.09	6.3
Preipitation												
2010-2039	7	0	6	2	5	0	4	2	3	6	6	4
2040-2069	13	-6	6	6	12	3	7	6	10	8	10	5
2070-2099	19	-1	18	11	19	2	6	9	10	6	1	7

Source: Price et al. (2011)

Table 6.4: Climate Change Projections for Prairies Semi-arid (Brown and Dark Brown Soil Zone)

CLIMATE VAR	SCENARIO A2 'PESSIMISTIC'				SCENARIO A1B 'MEDIUM'				SCENARIO B1 'OPTIMISTIC'			
Mean daily min	**Spring**	**Summer**	**Fall**	**Winter**	**Spring**	**Summer**	**Fall**	**Winter**	**Spring**	**Summer**	**Fall**	**Winter**
2010-2039	0.49	1.06	1.08	1.5	1.04	1.31	0.83	1.89	0.74	0.96	1.01	1.3
2040-2069	2.05	2.66	2.34	3.56	2.16	2.8	2.36	3.64	1.22	1.81	1.83	2.72
2070-2099	3.63	4.52	3.83	5.29	2.79	3.7	3.42	4.78	1.92	2.51	2.46	3.46
Mean daily max												
2010-2039	0.36	1.04	0.9	0.98	0.98	1.31	0.79	1.31	0.66	0.95	1.04	0.82
2040-2069	1.9	2.78	2.33	2.47	1.95	2.86	2.27	2.48	1.06	1.82	1.86	1.89
2070-2099	3.42	4.45	3.63	3.84	2.61	3.89	3.54	3.47	1.78	2.63	2.61	2.44
Mean daily												
2010-2039	0.85	2.1	1.98	2.48	2.02	2.62	1.62	3.2	1.4	1.91	2.05	2.12
2040-2069	3.95	5.44	4.67	6.03	4.11	5.66	4.63	6.12	2.28	3.63	3.69	4.61
2070-2099	7.05	8.97	7.46	9.13	5.4	7.59	6.96	8.25	3.7	5.14	5.07	5.9
Preipitation												
2010-2039	6	5	4	4	5	3	3	2	5	5	4	4
2040-2069	11	-6	5	6	9	6	8	4	10	10	5	6
2070-2099	17	5	15	11	15	5	4	8	10	8	1	7

Source: Price et al. (2011)

[36] Note the baseline for these projections is 1980 to 2009 temperature and precipitation.

6.5.1 A2 'Pessimistic' Scenario

Figures 6.5 through 6.7 illustrate the percentage change in area of each crop group from the base of wheat for the three soil zones. The results for the three soil zones have relatively consistent results, illustrating an increase in the share of canola, specialty oilseeds and summerfallow; however this share decreases through each time period. Wheat remains the preferred choice over the remaining crop groups of pulses, feed and forages. Similar to the preferred crop groups, the expected share of these crop groups continues to decrease through each time period. In the black soil zone, the share of forages over wheat remains relatively constant for the 2010 to 2039 time period and the 2070 to 2099 time period; however it experiences a drop in the middle time period. Perhaps this could be explained through the change in precipitation. In future time periods, precipitation reaches its lowest expected change in summer for this scenario, which could explain why there is a sharp drop. This same result was found for share of canola in the brown soil zone. Again, this time period experiences the only negative change in precipitation. Minimal rainfall in critical months can cause the plant to bolt, skipping important plant development stages, decreasing yield. Overall, there is an average decrease of 3.5% in the share of wheat in the black soil zone, and around 4.5% in both the dark brown soil zone and brown soil zone under this scenario by 2099, from the base year.

6.5.2 A1B 'Medium' Scenario

The second climate change scenario has the most consistent results through the projected climate change periods. Figures 6.8 through 6.10 illustrate these changes. Overall, the same choices of canola, specialty oilseeds and summerfallow are made over wheat throughout the time period. This choice is also made throughout the three future time periods. Pulses, feed and forages also have the same results, with a decrease in the share of these crop groups over wheat. Share of canola and forages do not exhibit the same jump in the middle time period as the previous scenario; however this scenario does not project any decreases in temperature or precipitation. By the year 2099, average wheat share is projected to fall by close to 3% in all three soil zones from the base year.

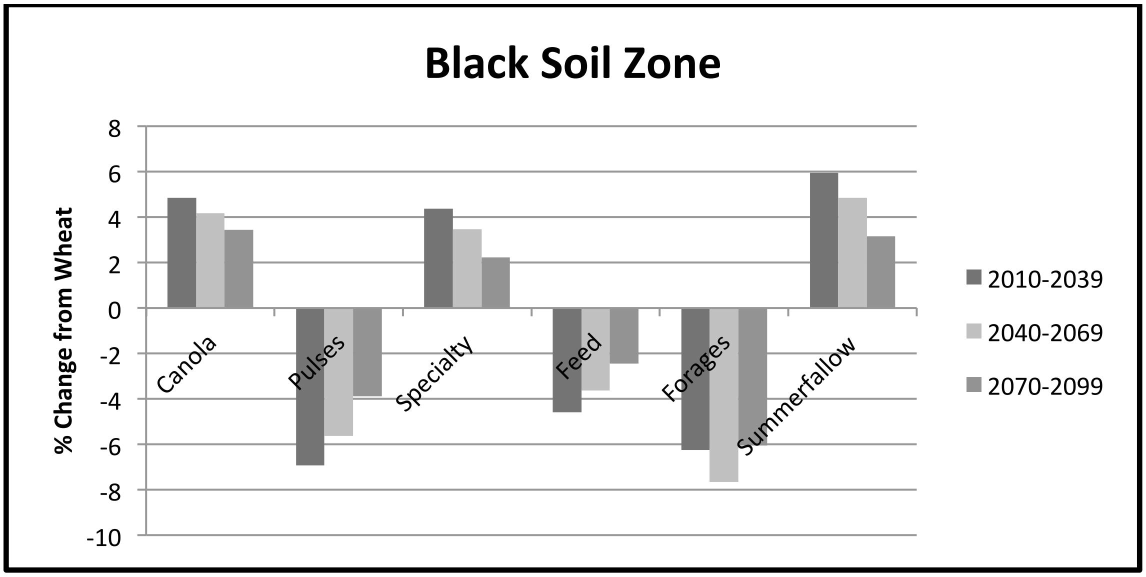


Figure 6.5: Percent Change in Choice from Wheat Group, Black Soil Zone, A2 Scenario

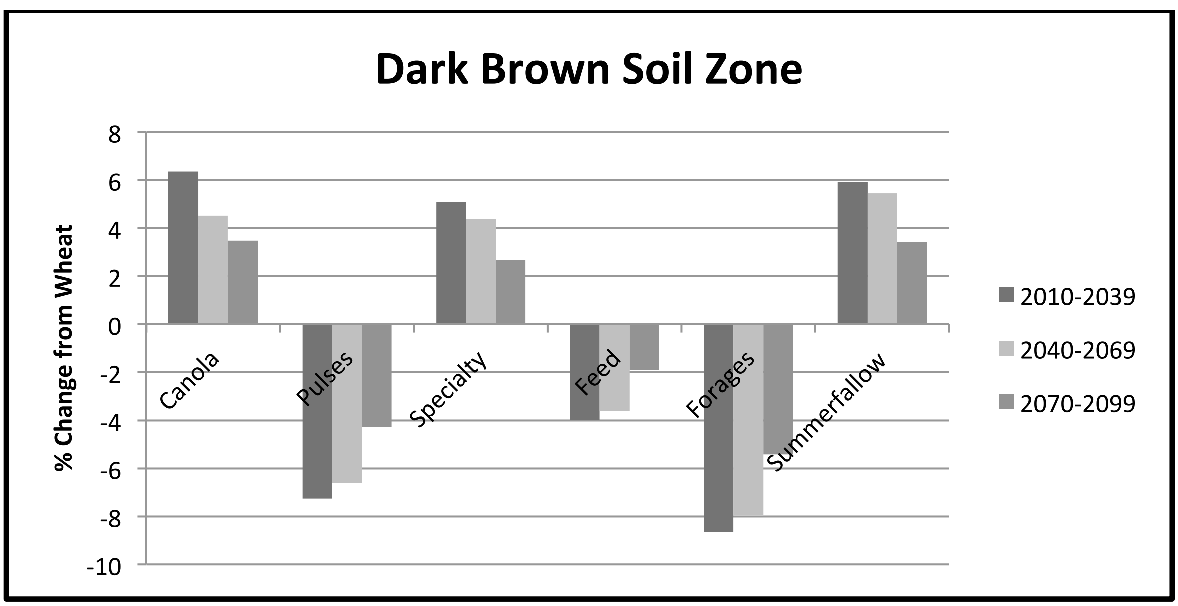


Figure 6.6: Percent Change in Choice from Wheat Group, Dark Brown Soil Zone, A2 Scenario

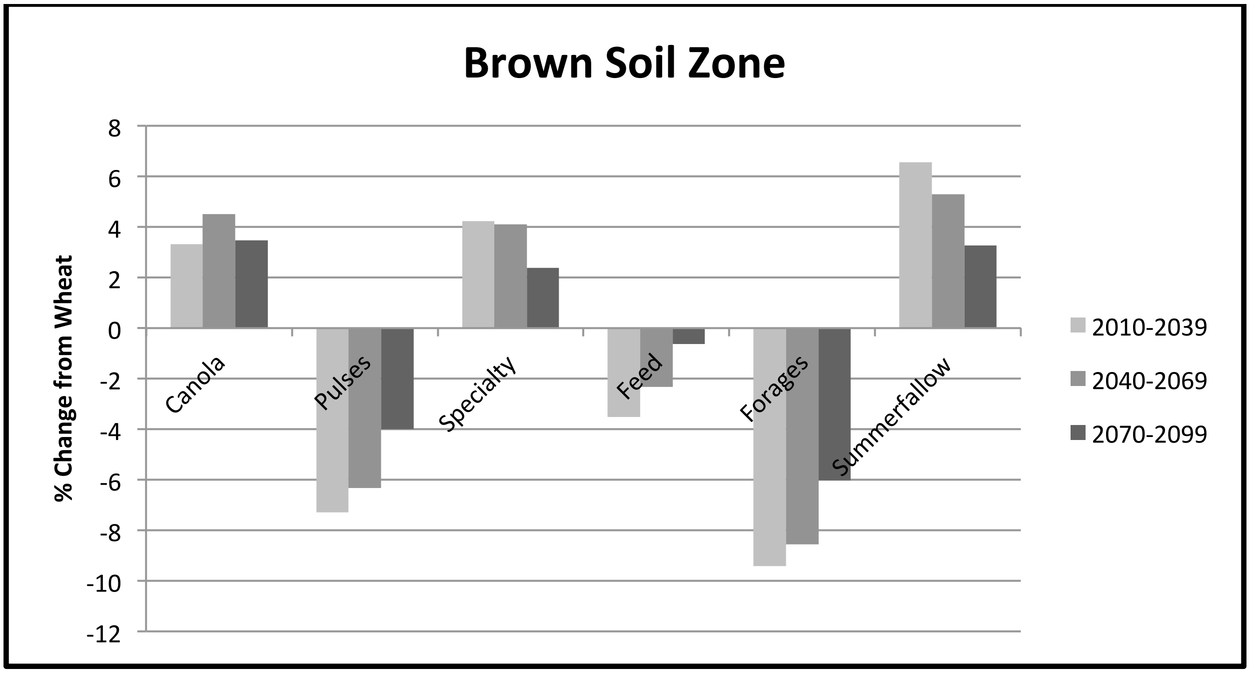


Figure 6.7: Percent Change in Choice from Wheat Group, Brown Soil Zone, A2 Scenario

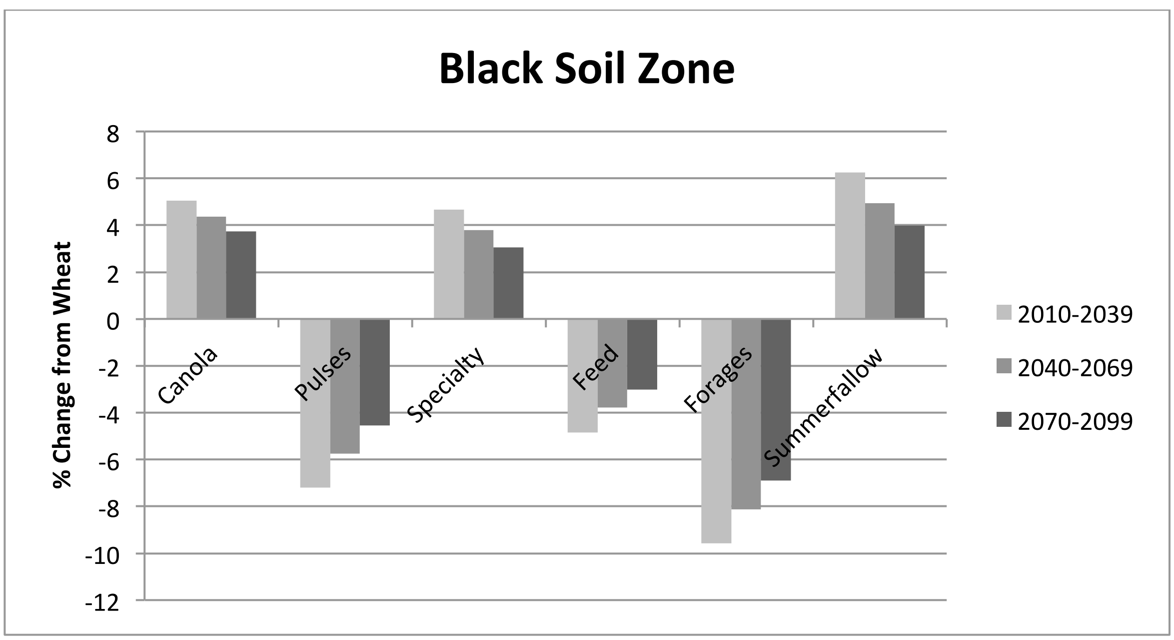


Figure 6.8: Percent Change in Choice from Wheat Group, Black Soil Zone, A1B Scenario

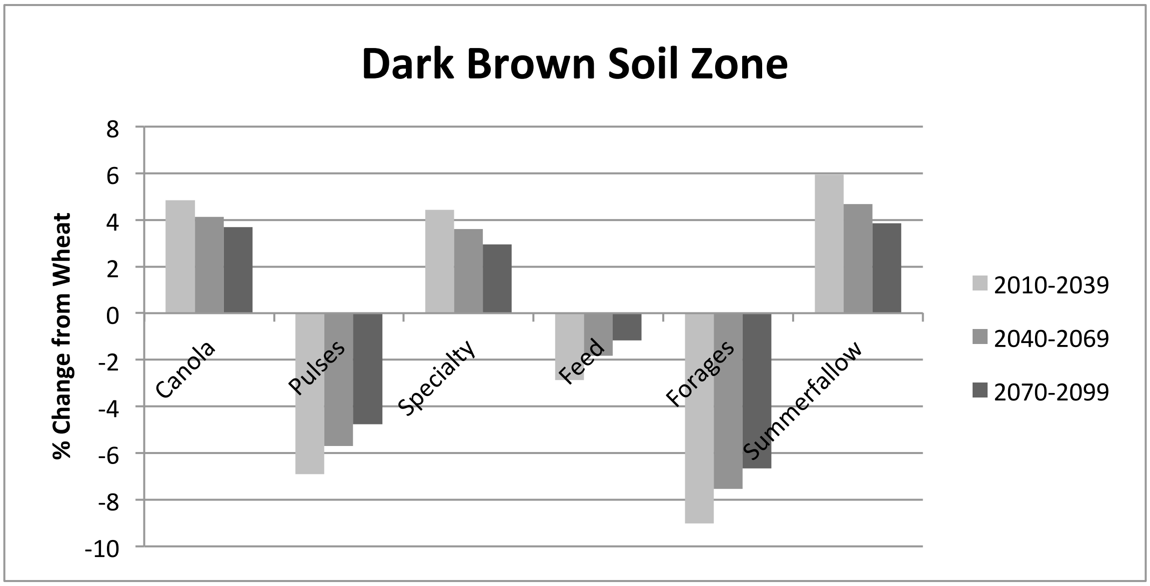


Figure 6.9: Percent Change in Choice from Wheat Group, Dark Brown Soil Zone, A1B Scenario

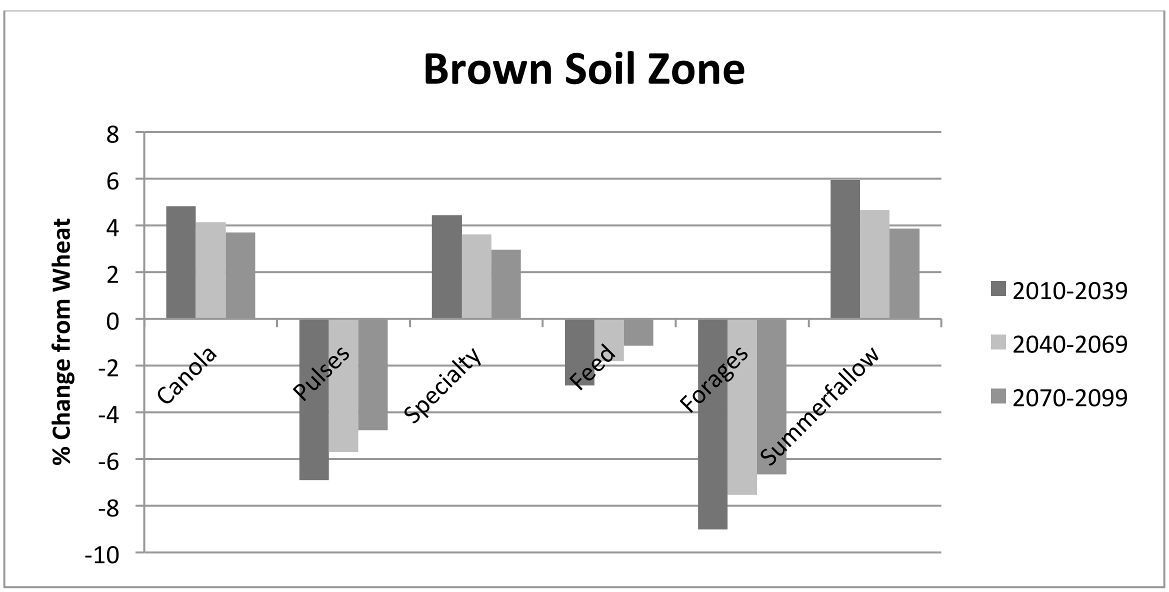


Figure 6.10: Percent Change in Choice from Wheat Group, Brown Soil Zone, A1B Scenario

6.5.3 B1 'Optimistic' Scenario

Figures 6.11 through 6.13 detail the percent change from the choice of wheat for the optimistic climate change scenario. The results are again consistent with the choice of canola, specialty and summerfallow being preferred over wheat and the remaining groups reflecting a preference for wheat. However, there are some inconsistencies among soil zones for some of the crop groups. In the black and brown soil zones, canola has the same trend as the previous scenarios. In the dark brown soil zone there is a staggering of canola share between the years with a slight drop in share before increasing again in the final time period. This same trend can be seen in the share of pulses, specialty oilseeds and forages for the dark brown soil zone. Again, the time period of 2040 to 2069 has a projected decrease in summer precipitation, which could affect this initial decrease in share. However, it does not explain why this same effect does not happen in the brown soil zone. Feed and specialty oilseeds for all three soil zones experience the same effect; however this finding is consistent throughout all the soil zones. Overall, there is a decrease in the share of wheat and by 2099 this decrease is at 3.6% in the black soil zone, 2.8% in the dark brown soil zone and 4% in the brown soil zone, from the base year.

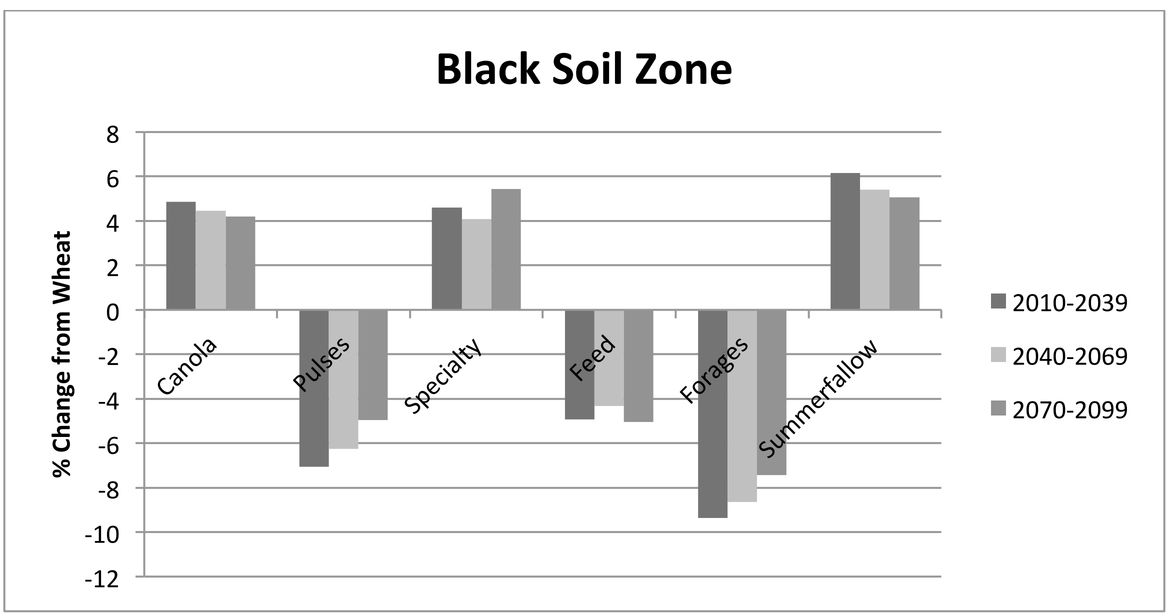


Figure 6.11: Percent Change in Choice from Wheat Group, Black Soil Zone, B1 Scenario

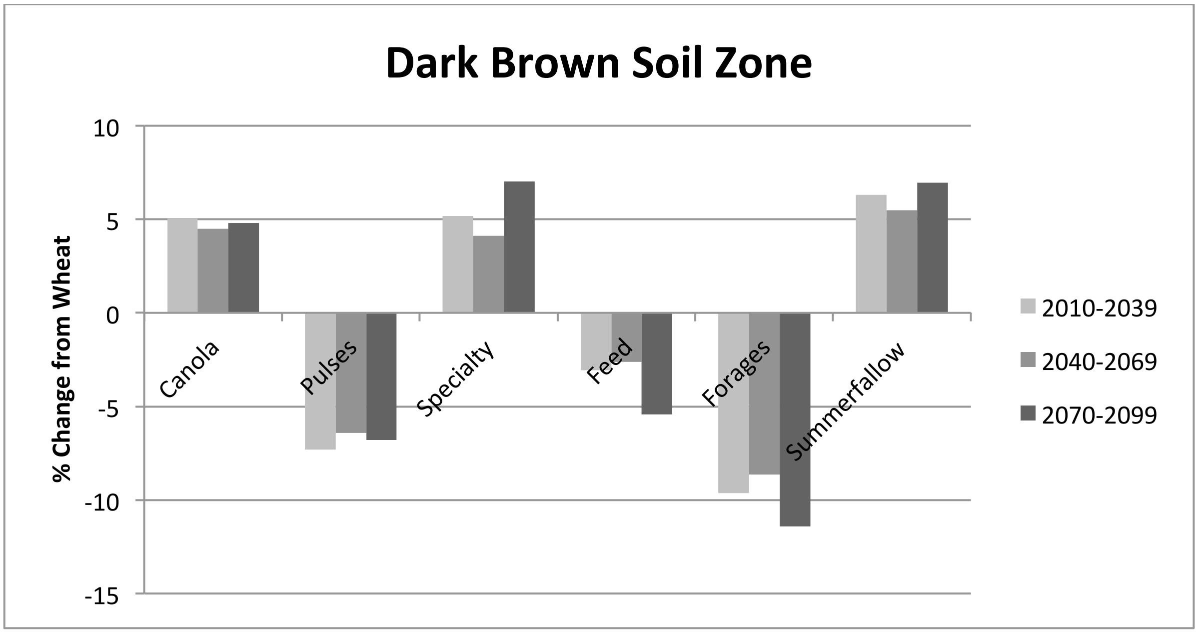


Figure 6.12: Percent Change in Choice from Wheat Group, Dark Brown Soil Zone, B1 Scenario

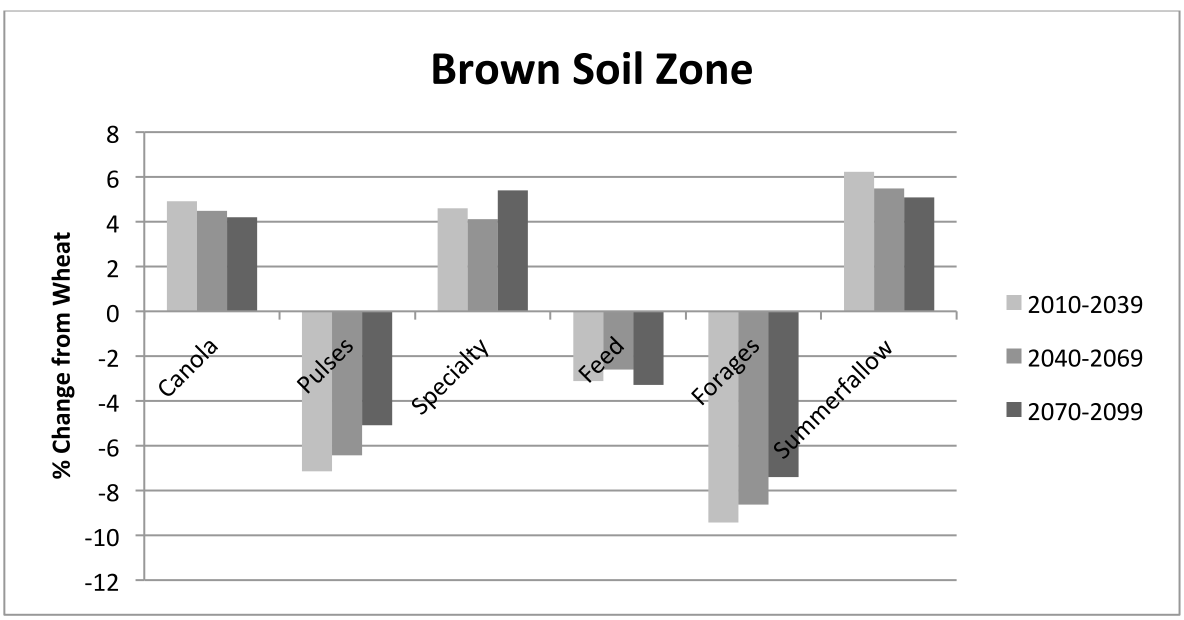


Figure 6.13: Percent Change in Choice from Wheat Group, Brown Soil Zone, B1 Scenario

6.6 Discussion of Simulation Results

Table 6.5 outlines the projected change in wheat area for the three different climate change scenarios by time period as well as total change. The trend of less area to wheat continues to decrease in each soil zone over the projected time period. Contrary to the current trend however, summerfallow area continues to increase. In fact, it is the one crop group whose area increases the most in all three soil zones and in all three future time periods. As expected, much of this area change comes from a switch to canola, which has been on the rise over the past several decades and is likely to continue. Pulses, on the other hand do not experience an increase in share in any scenario. This is not as expected since area of this crop has dramatically increased in recent years. However, pulses are a relatively new crop to Saskatchewan, especially chickpeas and lentils, therefore the use of them as an adaptation to climate change may be less attractive compared to the other crop groups.

Table 6.5: Projected Changes in Wheat Area (acres) from base year, 2000, by Soil Zone

	Black SZ			
	2010-2039	*2040-2069*	*2070-2099*	*TOTAL AVG .CHANGE*
Pessimistic	-2.56	-4.41	-3.57	-3.51
Medium	-5.62	-4.57	-3.67	-4.62
Optimistic	-5.72	-5.27	-2.72	-4.57
	Dark Brown SZ			
	2010-2039	*2040-2069*	*2070-2099*	*TOTAL AVG .CHANGE*
Pessimistic	-2.53	-3.83	-2.03	-2.80
Medium	-3.55	-2.62	-2.04	-2.74
Optimistic	-3.99	-3.59	-1.10	-2.89
	Brown SZ			
	2010-2039	*2040-2069*	*2070-2099*	*TOTAL AVG .CHANGE*
Pessimistic	-6.11	-3.31	-1.50	-3.64
Medium	-3.57	-2.64	-2.06	-2.76
Optimistic	-3.50	-3.61	-4.85	-3.99

Although pulses, feed and forages represent a negative change, this change is relatively slower in the pessimistic and medium scenarios. This could suggest that beyond 2099, given the same trend in climate change, these other crop groups may begin to be a viable option to add to the crop mix as an adaption strategy. The optimistic scenario outlines a slightly different story. The share of a specialty oilseed over wheat has the highest percentage change than any other scenario. In the last time period, this increase reached its maximum, suggesting that a specialty oilseed may be another viable option for adaptation to climate change. Forages appear to be a poor choice for adaption to climate change as it experiences the largest negative percentage change. Again, for the final time period in the optimistic scenario this decrease reaches a maximum of an over 10% decrease in the choice of forages. Summerfallow dominates in choice in all three scenarios and all three soil zones. As mentioned in the marginal effects discussion, farmers could chose fallow as an adaptation to climate change, and as the scenario results suggest, this choice of this continues to increase beyond most other crops.

6.7 Conclusion

This chapter focused on explaining the results of the estimated FMNL model and the simulation. From the FMNL model estimated marginal effects it was clear that temperatures in the spring and summer have a significant impact on crop choice. As hot weather increases, the choice to summerfallow also increases. The simulation further clarified that as temperatures and precipitation increases, the choice of summerfallow over wheat also increases. Canola and specialty oilseeds continue be the preferred choice over wheat, with pulses, feed and forages remaining the least preferred choice in a changing climate.

CHAPTER 7

CONCLUSION

7.1 Introduction

Climate change is evident from changes in average conditions as well as by changes in climate variation and extreme events (Lemmen et al., 2008). A majority of climate change research predicts a higher level of warming for the northern latitudes resulting in a longer and warmer growing season; however there are predictions of drying and increased evapotranspiration projected for midcontinent regions (Sauchyn & Kulshreshtha, 2007). Because weather is an important factor in crop production, agriculture is inherently sensitive to climate change. The general consensus for Saskatchewan is that these impacts would vary regionally (Lemmen & Warren, 2004). As a result, research has been conducted to assess the possible adaptation strategies to climate change in agriculture and crop production. One of the most common methods of adaptation at the farm level is switching the crop mix to crops more suitable to a changing climate.

The main objective of this study was to develop a model that would assess how farmers in Saskatchewan have been adapting to climate change by switching crops. To date, there has been little focus specifically on Saskatchewan, as most studies have analyzed Canada as a whole (Reinsborough, 2003; Weber & Hauer, 2003), or the Prairie Provinces (Amiraslany, 2010). Various models including the Ricardian model, the MNL model and more recently the FMNL model has been used to estimate the change in crop mix. The FMNL is an extension of choice modelling, the advantages over the Ricardian model is being able to model adaptation explicitly; and over the choice models for being able to use aggregate data and a fractional dependent variable. Fractional values, or shares, are common in many industries such as agriculture. For this reason, the FMNL was the most appropriate model to use to address the specific research question.

Based on choice theory, share of cropland in Saskatchewan devoted to seven specified crop groups was chosen to represent the dependent (or choice) variable. Based on an extensive literature review climatic, economic, socio-economic and geographic variables were chosen as explanatory variables to model the choice made by producers. Overall, the results suggest that prices, policy and land characteristics play an important role in a majority of crop choices. Cooler, dry springs are favourable for major crops such as wheat, canola and pulses; and when temperatures are high in the summer months the choice of summerfallow increases over the study period. Interestingly, precipitation did not have as much of an impact, as each equation had few significant precipitation coefficients.

The results were used in a simulation model to estimate how crop share may change under future climate scenarios. These results indicate that the current trend of a decrease in area allocated to wheat will continue; however, the area left to summerfallow will increase throughout the projected periods of climate change. The goal of this chapter is to briefly summarize the major conclusions of the study. Section 7.2 and 7.3 will discuss the major conclusions and the implications of the findings, respectively. Section 7.4 will discuss the study limitations and the possibility for improvement and future research.

7.2 Major Conclusions

The major conclusion from this research are: (i) following current trends, the area devoted to spring wheat and durum wheat is predicted to continue to decline into the future; (ii) area devoted to wheat remains a superior choice over pulses, feed and forages, while specialty oilseeds represent a viable alternative choice to wheat and (iii) most significantly, summerfallow area would increase. This is in contrast to the current trend of declining summerfallow area as a result of tighter crop rotations. This finding was observed throughout all three soil zones as well as for all three climate change projection periods. The average decline in the area of wheat from the base years of 2000 in the black soil zone by 2099 is 3.5% for the pessimistic scenario and 4.6% for both the medium and optimistic scenario. In the dark brown soil zone, the decline from the base year is 2.7% under the medium scenario, while the pessimistic scenario projects a decline of 2.8% and the optimistic scenario shows a decline of 2.9%. In the black soil zone, the decline in wheat area from the base year is 3.6% under the pessimistic scenario, 2.8% under the medium and 4% under the optimistic scenario. Overall, the projected decreases in area devoted to wheat are most prominent in the black and brown soil zones. The dark brown soil zone experiences the least variable decreases from one time period to another. In the black soil zone, wheat in the base year accounts for the least share of area out of all three soil zones; however, wheat area in the brown soil zone is the highest out of all three, therefore the projected decreases in area devoted to wheat could be significant in this soil zone.

7.3 Implications

As more area is allocated to summerfallow, as simulated, one of the major implications this would have will be felt by the Saskatchewan economy. If, as indicated by this modelling, summerfallow is currently one of the few possible choices as an adaptation response to an increased climate, the repercussions for Saskatchewan could be extreme at the individual farm as well as national levels. Chapter two outlined the importance of agriculture as well as the agri-food sector to the provincial and national economy. Area devoted to summerfallow means less crop is produced, this in turn is likely to have a detrimental effect on farmers, employees of the agri-food sector, as well as the economy of Saskatchewan and Canada. There are also the welfare effects of summerfallow due to increased soil erosion and decreased carbon sequestration. This could be further exacerbated by the projected extreme climate events. Given the results of this research, it could be suggested that new crop varieties should be developed to better withstand these types of extremes. Or another crop mix all together could be introduced. Overall, more research, development and extension services would be extremely beneficial to prepare for the possibilities that are faced with a changing climate.

7.4 Study Limitations and Future Research

This study suffered in some respects by a lack of guidance from the literature using the FMNL model for agricultural decisions. Although the conceptual model drew upon many fields of research including climate change, agriculture, choice and adaptation, no solid framework strictly concerning agriculture and the fractional choice model was found. This may have resulted in limited number of variables included in the study. Given more thorough and complete information, future studies may strive to identify for a better specification of the model.

One of the serious limitations of the present study is the use of prices as a guide to profitability. Although prices are important part of decision making, most farmers use financial margins from a given production process. Estimation of financial margins requires data on cost of production. For this type of a study, these data would have to be generated for various commodities in different parts of Saskatchewan over the study period. Such data are not routinely collected. As mentioned in the previous chapters, crops such as pulses and malting barley require more stringent management practices, affecting financial margins, which is likely to factor into area allocation and production decisions. On account of paucity of data on cost of production, financial margins for various crops in different parts of Saskatchewan could not be included in this study. It is hoped that future studies would attempt to remove this deficiency of this study.

There were two issues that emerged related to the results of the estimated model. These were: small magnitude of the marginal effects for the livestock inventories, and the minimal significance of precipitation variables. The small magnitude observed for the livestock inventories could be explained by the measure of this variable. These are large range in these values, as livestock inventory levels range from being small in some districts to larger in others. For the low significance of the precipitation variables, it could be speculated that farmers take the fact the Saskatchewan suffers from low and unreliable precipitation as given. Theory dictates that precipitation greatly influences crops, but choice of crops may not be. A better specification of the model and estimation method may overcome this limitation of the study.

Adoption of new technology as an adaptation strategy was not included in this study. Technology is considered a long-term adaptation strategy to climate change, and would take years to take effect (MNS, 1994, 1996). However, including the possibility of a new, robust crop groups that could withstand the projected weather extremes could substantially add to this model. Examples of these crops could be the current crop mix in warmer climates of the Northern U.S. such as sorghum, corn and/or soybeans.

In this study, all crops were treated as annual crops. However, forages are planted over multiple years, rather than being a year-to–year decision. Forages take planning and changes in management practices in order to allocate area to this crop. Taking these decisions into account would also further improve upon the model.

One of the major results of this study was an increase in summerfallow under a warmer climate. This issue deserves further examination. Some form of tillage usually accompanies leaving land to summerfallow; however there are different summerfallow management practices that farmers can employ on these fields. Some of these practices are more beneficial to the soil than others, and some are more expensive than others, such as 'chem' fallow[1]. Tillage methods could also be incorporated into the crop groups to account for different management practices. For example, conservation tillage

[1] Chem fallow, or chemical fallow, involves using herbicides such as glyphosate to kill the weeds on the land, without disturbing the soil using tillage practices. However, this technique can vary to include some tillage practices (U.S. Environmental Protection Agency, 2013).

leaves up to 30 percent of the previous crops soil residue on the surface, conserving moisture and lessening the possibility of erosion (U.S. Environmental Protection Agency, 2013). Others are less expensive options, like zero tillage or no till. Given that historical information is available for these practices, including these in estimation could improve future research.

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APPENDIX A

TREATMENT OF MISSING DATA ISSUES

A.1 Missing Data Issues

A.1.1 Livestock Inventory

Annual data by crop district was only available beginning in 1996 for hogs and cattle on farm; the remaining years (1981-1995) were available by census year. The census years also had total on farm livestock for the entire province of Saskatchewan. This data issue was resolved estimating the percentage of total hog and cattle in each district out of the total in Saskatchewan, and then interpolating between census years. For example, if Crop District 8 had 23.3 percent of the hog herd in the 1981 census year, they would have 23.3 percent of the total hog herd in 1982 and 1983. In the next census year if they had 23.5 percent of the total hog herd, they would have that same percentage for 1984 through 1988. In 1989, the next census year's percentage would be used. This was done for all crop districts for all missing years. The exception is with crop district 1A which had missing hog inventory data for 2001 to 2010. This was remedied by dividing each crop districts inventory by the Saskatchewan total to get percent by crop district, then using the missing percentage value to interpolate the share of the total hogs in Saskatchewan for district 1A.

A.1.2 Seeded Acreage

Seeded acreage data issues were addressed in the same way missing values for livestock industry was. In most cases data was close to complete and available for the crops spring wheat, durum, canola[37], peas, oats, barley and flaxseed. These issues also varied by crop district, as some crop districts are smaller than others and have more confidentiality restrictions on publicly available information. The few missing years that were present were remedied by using an average of the

[37] Canola seeded acreage information was unavailable for Crop District 7a from 1981 to 1990 and was completed by subtracting the seeded acreage from all other crops districts from the total seeded acreage in Saskatchewan for those years.

surrounding years or in cases when there were multiple years missing, averages of the previous four years were used. This was a rational way to account for these small data issues because four years would take into account crop rotation between other crops and/or summerfallow.

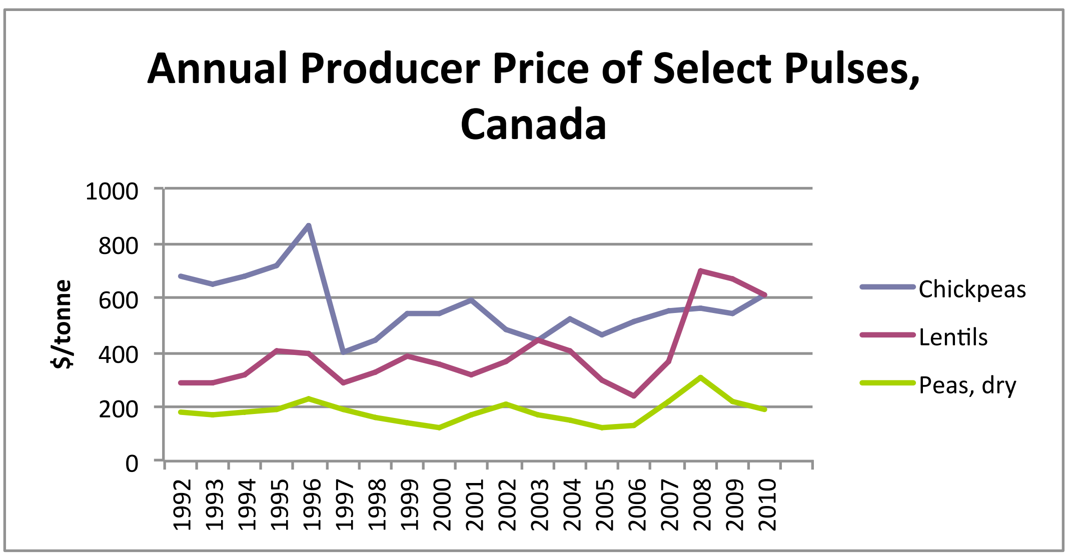
Fall rye and winter wheat also had some missing data issues, however these varied largely by crop district. In places where there were large sets of years missing these values remained at zero, however the years that were has surrounding data available were filled in by the same method as above. The major issue was with spring rye. The data for this crop was minimal and no crop district had full information. Therefore there were no corrections made to this data and values remained at zero for the missing years. Because these crops account for a small amount of total area and because they are summed into a feed group, this data issue was not critical if it was not ameliorated.

Lentil, dry pea, mustard seed and canary seed acreage data was available yearly from 1986 to 2010. The missing years were resolved by the same way livestock inventory values were -- by using share of total by crop district and interpolating for the missing years (1981-1985). For missing observations in the years 1986 to 2010, four year average of previous or surrounding years were used by the same logic as the previous crops. Chickpea area data was also a major issue, with minimal information available, varying by crop district. Where missing observations were only a few in the crop districts with available data, the same average method was applied as previously explained. In the crop districts that had four observations or fewer no steps were taken to correct this and the values remained at zero. Chickpeas still have minimal acreage and so data is difficult to obtain, they also account for least amount out of all the pulses and as the pulse group included total acreage for dry peas, lentil and chickpeas this was not a critical issue.

The final issue with the seeded acreage data was for summerfallow and forages. This information is not available yearly by crop district but by census year. Therefore the entire set of time series variables (1981-2010) were interpolated in the same manner as the aforementioned variables.

A.2 Pulse & Specialty Oilseeds Price movements

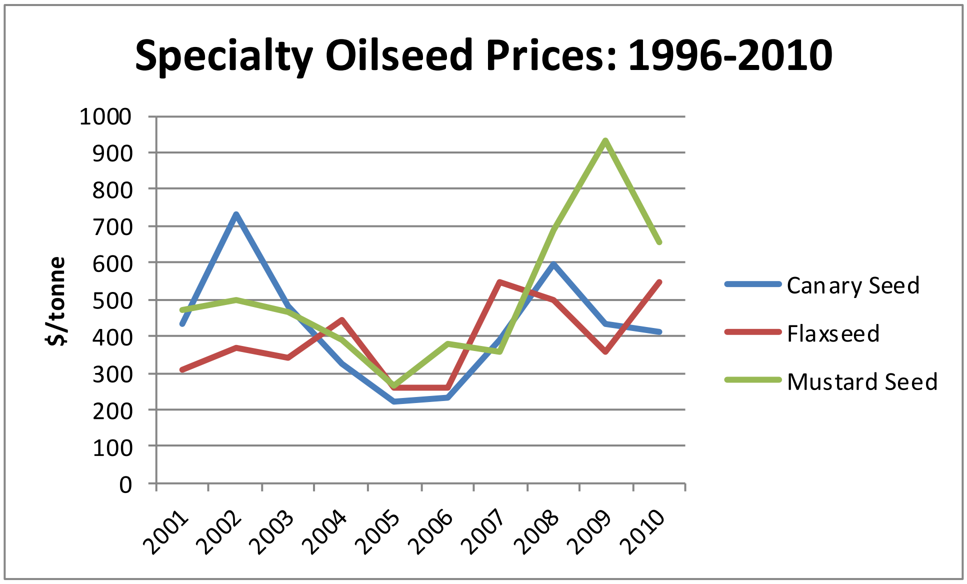
Figure A.1 shows the average annual producer price per tonne for chickpeas, lentils and dry peas. The information from this table was obtained from FAO STAT to illustrate how these prices tend to move together with the exception of a few peaks. Because Saskatchewan produces roughly 99% of this group, the Canadian producer price is acceptable.



Source: FAO Stat (2013)

Figure A.1: Annual Producer Prices in $/tonne for Chickpeas, Lentils and Peas, Canada, 1992-2010

Similarly, Figure A.2 shows the average annual producer price for canary seed, flaxseed and mustard seed. This data was obtained from the Saskatchewan Ministry of Agriculture, and illustrates how these prices also tend to move together.



Source: Saskatchewan Ministry of Agriculture (2013a)

Figure A.2: Annual Farm Price in $/tonne for Canary Seed, Flaxseed and Mustard Seed, Saskatchewan, 2001-2010

APPENDIX B

VARIABLE DEFINITIONS

Table B.1: Variable Definitions

Variable	Variable Group	Definition
JT	Climatic	January temperature
AT		April temperature
JuT		July temperature
OT		October temperature
JP		January precipitation
AP		April precipitation
JuP		July precipitation
OP		October precipitation
JT^2		January temperature squared
AT^2		April temperature squared
JuT^2		July temperature squared
OT^2		October temperature squared
JP^2		January precipitation squared
AP^2		April precipitation squared
JuP^2		July precipitation squared
OP^2		October precipitation squared
JT*JP		January temperature multiplied by January Precipitation
AT*AP		April temperature multiplied by April Precipitation
JuT*JuP		July temperature multiplied by July Precipitation
OT*OP		October temperature multiplied by October Precipitation
I_{beef}	Economic	Beef inventory
I_{pig}		Pig inventory
P_{WG}		Average price of wheat group
P_{CG}		Average price of canola group
P_{PG}		Average price of pulse group
P_{FG}		Average price of forages group
P_{SG}		Average price of specialty oilseeds group
P_{FO}		Average price of forages group
D_{CN}	Policy/Socio-Economic	Crows Nest Past Agreement
D_{oats}		Oats markted through the CWB
D_{PCP}		Permant Cover Program
D_{DBSZ}	Geographic	Dark brown soil zone
D_{BRSZ}		Brown soil zone

APPENDIX C

COMPLETE STUDY RESULTS

C.1 STATA Print Outs

C.1.1. Descriptive Statistics

	x	mean	sd	min	max
jant	-13.4	-13.4	5.841	-29.7	6.6
aprt	4.853	4.853	3.301	-4.7	20.1
julyt	18.35	18.35	1.649	14.2	24.3
octt	3.897	3.897	3.928	-21.8	9.6
janp	16.91	16.91	10.35	0	75.4
aprp	26.46	26.46	20.35	0	140.6
julyp	64.34	64.34	39.64	2.8	205.8
oct	23.64	23.64	17.87	0	103.7
jant2	213.6	213.6	149.3	.25	882.1
aprt2	34.41	34.41	55.54	0	404
julyt2	339.5	339.5	61.35	201.6	590.5
octt2	30.57	30.57	47.9	0	475.2
janp2	392.8	392.8	527	0	5685
aprp2	1113	1113	1917	0	2.0e+04
julyp2	5706	5706	6770	7.84	4.2e+04
octp2	877	877	1396	0	1.1e+04
janjan	-235	-235	198	-1093	244.5
aprapr	142	142	213.6	-84.6	1950
julyjuly	1157	1157	698.1	68.04	4075
octoct	93.7	93.7	110	-391.9	535.6
beef	2.4e+05	2.4e+05	1.6e+05	1.4e+04	7.6e+05
pigs	7.9e+04	7.9e+04	8.0e+04	0	5.5e+05
dbsz	.3636	.3636	.4818	0	1
brsz	.2727	.2727	.446	0	1
oatscwb	.3	.3	.459	0	1
crowsnest	.1	.1	.3005	0	1
pcp	.1333	.1333	.3405	0	1
pw	171.4	171.4	35.98	115.5	268.5
pc	309.6	309.6	50.2	240	439.3
pp	258.9	258.9	41.63	202	417.2
ps	306.9	306.9	71.22	196.8	470.4
pf	118.9	118.9	22.8	87.42	179.7
th	73.54	73.54	10.99	54.33	99.67

C.1.2 FMLOGIT Model 1

```
Iteration 0:   log pseudolikelihood = -551.86241
Iteration 1:   log pseudolikelihood = -541.74288
Iteration 2:   log pseudolikelihood =  -541.0431
Iteration 3:   log pseudolikelihood = -541.03955
Iteration 4:   log pseudolikelihood = -541.03955

ML fit of fractional multinomial logit          Number of obs   =        330
                                                Wald chi2(120)  =    1977.69
Log pseudolikelihood = -541.03955               Prob > chi2     =     0.0000
```

	Coef.	Robust Std. Err.	z	P>|z|	[95% Conf.	Interval]
eta_canola						
jant	-.146542	.0593921	-2.47	0.014	-.2629484	-.0301356
aprt	-.1574184	.0419832	-3.75	0.000	-.239704	-.0751328
julyt	.1025982	.6989363	0.15	0.883	-1.267292	1.472488
octt	.0055262	.0414438	0.13	0.894	-.0757021	.0867545
janp	-.0023712	.0242913	-0.10	0.922	-.0499812	.0452388
aprp	-.0019601	.006032	-0.32	0.745	-.0137826	.0098625
julyp	.0432184	.0214305	2.02	0.044	.0012154	.0852213
oct	.0248709	.0118945	2.09	0.037	.0015581	.0481838
jant2	-.0037205	.0017289	-2.15	0.031	-.0071091	-.0003318
aprt2	.0162129	.003168	5.12	0.000	.0100038	.022422
julyt2	-.001581	.0183217	-0.09	0.931	-.0374908	.0343289
octt2	.000899	.0015995	0.56	0.574	-.0022361	.004034
janp2	-.000129	.0002523	-0.51	0.609	-.0006236	.0003656
aprp2	.0001114	.0000588	1.90	0.058	-3.81e-06	.0002266
julyp2	-.0000552	.0000276	-2.00	0.045	-.0001092	-1.18e-06
octp2	-.0001188	.0001131	-1.05	0.294	-.0003405	.0001029
janjan	-.0011508	.0011065	-1.04	0.298	-.0033195	.0010178
aprapr	.0002665	.0006462	0.41	0.680	-.0010001	.001533
julyjuly	-.0018815	.0011145	-1.69	0.091	-.0040659	.000303
octoct	-.0017254	.0013306	-1.30	0.195	-.0043333	.0008825
_cons	-4.605506	6.63612	-0.69	0.488	-17.61206	8.401051
eta_pulses						
jant	-.0946569	.0535369	-1.77	0.077	-.1995873	.0102734
aprt	-.0782487	.0545739	-1.43	0.152	-.1852116	.0287143
julyt	-.6210877	.8052674	-0.77	0.441	-2.199383	.9572074
octt	-.0260742	.0547439	-0.48	0.634	-.1333702	.0812219
janp	-.0540688	.0287546	-1.88	0.060	-.1104269	.0022892
aprp	-.007067	.007714	-0.92	0.360	-.0221862	.0080522
julyp	.012638	.032148	0.39	0.694	-.050371	.0756471
oct	-.0010365	.0143738	-0.07	0.943	-.0292085	.0271355
jant2	-.0045799	.0019028	-2.41	0.016	-.0083093	-.0008506
aprt2	.0033626	.003963	0.85	0.396	-.0044047	.0111299
julyt2	.0163301	.0200686	0.81	0.416	-.0230037	.0556639
octt2	.0039988	.0024377	1.64	0.101	-.000779	.0087765

janp2	.0002272	.0003151	0.72	0.471	-.0003903	.0008448
aprp2	.0000967	.0000798	1.21	0.226	-.0000597	.0002531
julyp2	-.0000336	.0000435	-0.77	0.439	-.0001188	.0000516
octp2	-.0000941	.0001751	-0.54	0.591	-.0004373	.0002491
janjan	-.0030272	.0014032	-2.16	0.031	-.0057775	-.000277
aprapr	.0006905	.0009087	0.76	0.447	-.0010905	.0024715
julyjuly	-.000837	.0015304	-0.55	0.584	-.0038366	.0021625
octoct	.0001272	.0017281	0.07	0.941	-.0032599	.0035142
_cons	4.270457	8.120942	0.53	0.599	-11.6463	20.18721
eta_specialty						
jant	-.1200589	.0492388	-2.44	0.015	-.2165653	-.0235526
aprt	-.0555652	.0389338	-1.43	0.154	-.131874	.0207436
julyt	-.3641354	.6336198	-0.57	0.566	-1.606007	.8777365
octt	-.0588379	.0445489	-1.32	0.187	-.1461521	.0284763
janp	-.0048274	.0224328	-0.22	0.830	-.0487949	.0391401
aprp	.0024463	.0061802	0.40	0.692	-.0096668	.0145594
julyp	-.0148689	.019507	-0.76	0.446	-.0531019	.0233641
oct	.0073322	.0112721	0.65	0.515	-.0147608	.0294251
jant2	-.0036771	.0014857	-2.48	0.013	-.0065889	-.0007652
aprt2	.0040686	.0036682	1.11	0.267	-.0031209	.0112581
julyt2	.0086255	.0161283	0.53	0.593	-.0229855	.0402365
octt2	.0008628	.0015219	0.57	0.571	-.0021201	.0038458
janp2	.0000505	.0001982	0.25	0.799	-.000338	.000439
aprp2	-.0000223	.0000726	-0.31	0.759	-.0001646	.00012
julyp2	-.0000128	.0000268	-0.48	0.633	-.0000653	.0000397
octp2	-.0001464	.000124	-1.18	0.238	-.0003894	.0000965
janjan	-.0011189	.0011406	-0.98	0.327	-.0033545	.0011167
aprapr	.0004576	.0007584	0.60	0.546	-.0010288	.001944
julyjuly	.0007779	.000988	0.79	0.431	-.0011585	.0027142
octoct	.0012949	.0013774	0.94	0.347	-.0014048	.0039946
_cons	.6522881	6.192107	0.11	0.916	-11.48402	12.78859
eta_feed						
jant	-.0635577	.026847	-2.37	0.018	-.1161768	-.0109386
aprt	-.1222172	.0256288	-4.77	0.000	-.1724488	-.0719857
julyt	.0545922	.3725728	0.15	0.884	-.6756371	.7848216
octt	-.0303426	.0215882	-1.41	0.160	-.0726547	.0119694
janp	.0080604	.012152	0.66	0.507	-.0157572	.031878
aprp	.001365	.0039674	0.34	0.731	-.0064108	.0091409
julyp	.0312232	.0106593	2.93	0.003	.0103314	.0521149
oct	.005675	.0073438	0.77	0.440	-.0087186	.0200687
jant2	-.0013629	.0008163	-1.67	0.095	-.0029628	.0002369
aprt2	.010163	.0018698	5.44	0.000	.0064982	.0138279
julyt2	.0015585	.0095186	0.16	0.870	-.0170975	.0202145
octt2	-.0009524	.0008126	-1.17	0.241	-.002545	.0006402
janp2	-.0002167	.0001757	-1.23	0.217	-.000561	.0001276
aprp2	.0000367	.000043	0.85	0.394	-.0000476	.0001209
julyp2	-.0000195	.0000148	-1.32	0.185	-.0000485	9.38e-06
octp2	-3.13e-06	.0000731	-0.04	0.966	-.0001465	.0001402
janjan	-.0005283	.0006091	-0.87	0.386	-.0017221	.0006654
aprapr	.0000293	.0004063	0.07	0.943	-.000767	.0008256
julyjuly	-.0015084	.0005658	-2.67	0.008	-.0026173	-.0003995
octoct	-.0004524	.0007695	-0.59	0.557	-.0019607	.0010558
_cons	-3.265116	3.593825	-0.91	0.364	-10.30888	3.778651
eta_tamehay						
jant	-.0327811	.031831	-1.03	0.303	-.0951687	.0296065
aprt	-.0691056	.0364986	-1.89	0.058	-.1406416	.0024303
julyt	-.4095731	.4377099	-0.94	0.349	-1.267469	.4483226
octt	.0372575	.03325	1.12	0.262	-.0279114	.1024264
janp	-.007772	.0160566	-0.48	0.628	-.0392422	.0236983
aprp	.0047879	.0052939	0.90	0.366	-.005588	.0151638
julyp	.0275431	.0146643	1.88	0.060	-.0011983	.0562845
oct	.0215885	.0102741	2.10	0.036	.0014516	.0417254
jant2	-.0013158	.0010098	-1.30	0.193	-.003295	.0006635
aprt2	.0066355	.0022799	2.91	0.004	.002167	.011104
julyt2	.0141745	.0111457	1.27	0.203	-.0076706	.0360196
octt2	.0016998	.0011724	1.45	0.147	-.000598	.0039976

julyt2	.0141745	.0111457	1.27	0.203	-.0076706	.0360196
octt2	.0016998	.0011724	1.45	0.147	-.000598	.0039976
janp2	-7.45e-06	.0002076	-0.04	0.971	-.0004143	.0003995
aprp2	.0000329	.0000491	0.67	0.503	-.0000634	.0001291
julyp2	-.000029	.0000204	-1.43	0.154	-.0000689	.0000109
octp2	-.0001696	.0000999	-1.70	0.090	-.0003655	.0000262
janjan	-.0009263	.0007502	-1.23	0.217	-.0023967	.000544
aprapr	-.0002255	.00062	-0.36	0.716	-.0014407	.0009897
julyjuly	-.0013286	.0007404	-1.79	0.073	-.0027797	.0001225
octoct	-.0007427	.001019	-0.73	0.466	-.0027398	.0012545
_cons	.2268203	4.275086	0.05	0.958	-8.152195	8.605836
eta_summerfallow						
jant	.0427926	.0173728	2.46	0.014	.0087425	.0768427
aprt	.0424721	.0185977	2.28	0.022	.0060212	.0789229
julyt	.3604815	.240949	1.50	0.135	-.1117699	.8327329
octt	.0547571	.0143852	3.81	0.000	.0265626	.0829516
janp	-.0017651	.0086043	-0.21	0.837	-.0186292	.0150991
aprp	-.0010153	.0026874	-0.38	0.706	-.0062825	.0042519
julyp	.0068346	.0069707	0.98	0.327	-.0068276	.0204968
oct	-.0000779	.0041484	-0.02	0.985	-.0082087	.0080529
jant2	.0015321	.0004433	3.46	0.001	.0006633	.0024008
aprt2	-.0037416	.0014029	-2.67	0.008	-.0064912	-.0009921
julyt2	-.0089107	.0060465	-1.47	0.141	-.0207615	.0029402
octt2	-.0003542	.0007436	-0.48	0.634	-.0018116	.0011033
janp2	.0002542	.0001069	2.38	0.017	.0000446	.0004638
aprp2	-.0000199	.0000292	-0.68	0.496	-.0000771	.0000373
julyp2	3.64e-06	7.96e-06	0.46	0.647	-.000012	.0000192
octp2	.0000183	.0000386	0.48	0.635	-.0000573	.000094
janjan	.0003848	.00046	0.84	0.403	-.0005167	.0012863
aprapr	.0001221	.0003607	0.34	0.735	-.0005848	.0008289
julyjuly	-.000425	.0003533	-1.20	0.229	-.0011175	.0002675
octoct	-.0003963	.000485	-0.82	0.414	-.0013468	.0005543
_cons	-3.928148	2.355721	-1.67	0.095	-8.545276	.6889804

C.1.3 FMLOGIT Model 2

```
Iteration 0:   log pseudolikelihood = -551.86241
Iteration 1:   log pseudolikelihood = -519.80891
Iteration 2:   log pseudolikelihood = -516.31413
Iteration 3:   log pseudolikelihood = -516.08369
Iteration 4:   log pseudolikelihood = -516.05578
Iteration 5:   log pseudolikelihood = -516.05333
Iteration 6:   log pseudolikelihood =  -516.0533

ML fit of fractional multinomial logit          Number of obs   =        330
                                                Wald chi2(198)  =   15229.13
Log pseudolikelihood =  -516.0533               Prob > chi2     =     0.0000
```

	Coef.	Robust Std. Err.	z	P>|z|	[95% Conf.	Interval]
eta_canola						
jant	-.0377814	.0280401	-1.35	0.178	-.092739	.0171762
aprt	-.0805021	.031228	-2.58	0.010	-.1417078	-.0192964
julyt	.2929942	.3936601	0.74	0.457	-.4785655	1.064554
octt	.04483	.0185283	2.42	0.016	.0085153	.0811448
janp	-.0038309	.0160942	-0.24	0.812	-.035375	.0277132
aprp	-.0019122	.0034031	-0.56	0.574	-.0085822	.0047578

julyp	.0118522	.0117577	1.01	0.313	-.0111924	.0348969
oct	.0094387	.006747	1.40	0.162	-.0037851	.0226626
jant2	-.0010332	.0008435	-1.22	0.221	-.0026865	.0006201
aprt2	.005912	.0019721	3.00	0.003	.0020467	.0097773
julyt2	-.0084273	.0104553	-0.81	0.420	-.0289193	.0120648
octt2	.0003679	.0007961	0.46	0.644	-.0011925	.0019282
janp2	6.32e-07	.0001426	0.00	0.996	-.0002788	.0002801
aprp2	.000036	.0000323	1.11	0.266	-.0000274	.0000993
julyp2	-.0000201	.0000153	-1.31	0.189	-.0000501	9.91e-06
octp2	-.0000114	.0000584	-0.20	0.845	-.000126	.0001031
janjan	-9.07e-06	.0006154	-0.01	0.988	-.0012151	.001197
aprapr	-.0000322	.0003423	-0.09	0.925	-.0007031	.0006387
julyjuly	-.0006458	.0006259	-1.03	0.302	-.0018726	.000581
octoct	-.0015579	.0006242	-2.50	0.013	-.0027813	-.0003346
beef	1.17e-07	2.28e-07	0.51	0.609	-3.30e-07	5.64e-07
pigs	2.05e-06	3.47e-07	5.91	0.000	1.37e-06	2.73e-06
dbsz	-.8529607	.0892844	-9.55	0.000	-1.027955	-.6779666
brsz	-2.374904	.1881881	-12.62	0.000	-2.743745	-2.006062
oatscwb	-.729556	.1466238	-4.98	0.000	-1.016933	-.4421787
crowsnest	-.3448785	.282318	-1.22	0.222	-.8982116	.2084546
pcp	-1.027707	.1654669	-6.21	0.000	-1.352017	-.7033982
pw	-.0075818	.0055272	-1.37	0.170	-.0184149	.0032512
pc	.0019621	.0017878	1.10	0.272	-.0015419	.0054662
pp	.0060961	.0018335	3.32	0.001	.0025025	.0096897
ps	-.0068697	.0016254	-4.23	0.000	-.0100555	-.0036839
pf	.0197044	.0097529	2.02	0.043	.0005891	.0388197
th	.0277319	.0076666	3.62	0.000	.0127056	.0427582
_cons	-6.353541	3.684255	-1.72	0.085	-13.57455	.8674661
eta_pulses						
jant	.0378018	.0331974	1.14	0.255	-.027264	.1028675
aprt	-.1015947	.041763	-2.43	0.015	-.1834487	-.0197407
julyt	-.3803456	.3884202	-0.98	0.327	-1.141635	.380944
octt	.0169531	.0263352	0.64	0.520	-.0346629	.0685692
janp	-.0168349	.015395	-1.09	0.274	-.0470086	.0133388
aprp	-.0089476	.0050967	-1.76	0.079	-.018937	.0010418
julyp	-.0058764	.017618	-0.33	0.739	-.0404071	.0286542
oct	.0052269	.0089224	0.59	0.558	-.0122606	.0227144
jant2	.0013298	.001147	1.16	0.246	-.0009184	.003578
aprt2	.0047128	.0025433	1.85	0.064	-.0002719	.0096975
julyt2	.0093816	.0098226	0.96	0.340	-.0098703	.0286335
octt2	-.0005439	.0011909	-0.46	0.648	-.0028781	.0017903
janp2	6.45e-06	.0001476	0.04	0.965	-.0002828	.0002957
aprp2	.0000713	.0000474	1.50	0.132	-.0000216	.0001642
julyp2	.0000194	.0000243	0.80	0.425	-.0000282	.000067
octp2	-.000061	.0000816	-0.75	0.455	-.000221	.000099
janjan	-.0007464	.0007703	-0.97	0.333	-.0022562	.0007634
aprapr	-.0001151	.0004138	-0.28	0.781	-.000926	.0006958
julyjuly	-.0000779	.0008523	-0.09	0.927	-.0017484	.0015926
octoct	-.0008963	.0007773	-1.15	0.249	-.0024197	.0006271
beef	5.78e-07	2.77e-07	2.09	0.037	3.50e-08	1.12e-06
pigs	5.03e-09	4.45e-07	0.01	0.991	-8.68e-07	8.78e-07
dbsz	.2768548	.1130638	2.45	0.014	.0552538	.4984558
brsz	.1309951	.1238093	1.06	0.290	-.1116667	.3736569
oatscwb	-2.22569	.1978093	-11.25	0.000	-2.613389	-1.837991
crowsnest	-2.502607	.3074433	-8.14	0.000	-3.105184	-1.900029
pcp	-1.866074	.1946865	-9.59	0.000	-2.247652	-1.484495
pw	.0148716	.0079032	1.88	0.060	-.0006184	.0303616
pc	-.0057207	.0023993	-2.38	0.017	-.0104233	-.0010181
pp	.0150012	.0023637	6.35	0.000	.0103684	.019634
ps	-.0098674	.0019918	-4.95	0.000	-.0137713	-.0059634
pf	-.0060191	.014	-0.43	0.667	-.0334587	.0214205
th	.0732553	.0091114	8.04	0.000	.0553972	.0911134
_cons	-3.335845	3.883836	-0.86	0.390	-10.94802	4.276333

eta_specialty						
jant	-.0128547	.03285	-0.39	0.696	-.0772394	.0515301
aprt	-.03576	.0365891	-0.98	0.328	-.1074732	.0359533
julyt	.3045788	.5483767	0.56	0.579	-.7702198	1.379377
octt	-.0028202	.0336715	-0.08	0.933	-.0688152	.0631748
janp	.0200653	.0182568	1.10	0.272	-.0157174	.0558479
aprp	.0043561	.0049146	0.89	0.375	-.0052763	.0139884
julyp	-.0141328	.0142266	-0.99	0.321	-.0420165	.0137509
oct	.0107556	.0085684	1.26	0.209	-.0060381	.0275493
jant2	-.0000572	.0010211	-0.06	0.955	-.0020584	.0019441
aprt2	-.0007153	.0026977	-0.27	0.791	-.0060026	.0045721
julyt2	-.0093112	.0139247	-0.67	0.504	-.0366031	.0179806
octt2	-.0010193	.0011921	-0.86	0.393	-.0033558	.0013172
janp2	-.0000505	.0001302	-0.39	0.698	-.0003057	.0002047
aprp2	-.000086	.0000548	-1.57	0.116	-.0001934	.0000214
julyp2	-5.39e-06	.0000174	-0.31	0.757	-.0000396	.0000288
octp2	-.0001099	.0000792	-1.39	0.165	-.0002651	.0000452
janjan	.0006467	.0008903	0.73	0.468	-.0010983	.0023917
aprapr	.0001573	.0006848	0.23	0.818	-.0011849	.0014995
julyjuly	.000683	.0007184	0.95	0.342	-.000725	.0020909
octoct	.0003333	.0008871	0.38	0.707	-.0014054	.0020719
beef	-2.02e-06	2.67e-07	-7.57	0.000	-2.54e-06	-1.50e-06
pigs	1.28e-06	4.51e-07	2.83	0.005	3.91e-07	2.16e-06
dbsz	-.2865922	.0840148	-3.41	0.001	-.4512583	-.1219262
brsz	-.568471	.1103397	-5.15	0.000	-.7847327	-.3522092
oatscwb	-.7919159	.1224009	-6.47	0.000	-1.031817	-.5520146
crowsnest	-.6833502	.2236993	-3.05	0.002	-1.121793	-.2449077
pcp	-.9018273	.1524454	-5.92	0.000	-1.200615	-.6030398
pw	-.0000212	.0066223	-0.00	0.997	-.0130008	.0129583
pc	-.003722	.0025562	-1.46	0.145	-.0087321	.0012881
pp	.0022512	.0017904	1.26	0.209	-.001258	.0057604
ps	-.0016582	.0017878	-0.93	0.354	-.0051622	.0018458
pf	.0079124	.0107103	0.74	0.460	-.0130794	.0289042
th	.026354	.007133	3.69	0.000	.0123735	.0403344
_cons	-5.681373	5.35606	-1.06	0.289	-16.17906	4.816311
eta_feed						
jant	-.0109884	.0199108	-0.55	0.581	-.0500128	.028036
aprt	-.0559622	.0225014	-2.49	0.013	-.1000642	-.0118602
julyt	-.299041	.2407173	-1.24	0.214	-.7708383	.1727562
octt	-.0050172	.017195	-0.29	0.770	-.0387188	.0286843
janp	.0048267	.0088706	0.54	0.586	-.0125593	.0222127
aprp	-.0004075	.0026184	-0.16	0.876	-.0055395	.0047245
julyp	.0173809	.0069541	2.50	0.012	.0037513	.0310106
oct	-.0001074	.0052116	-0.02	0.984	-.010322	.0101072
jant2	.0000264	.0005916	0.04	0.964	-.0011331	.0011859
aprt2	.0038306	.0020033	1.91	0.056	-.0000957	.007757
julyt2	.0096692	.0061559	1.57	0.116	-.0023962	.0217346
octt2	-.0010139	.0006906	-1.47	0.142	-.0023675	.0003398
janp2	-.0001055	.0001025	-1.03	0.303	-.0003064	.0000954
aprp2	.0000252	.0000275	0.92	0.360	-.0000287	.000079
julyp2	-6.16e-06	.0000102	-0.60	0.547	-.0000262	.0000139
octp2	.0000453	.0000483	0.94	0.348	-.0000494	.00014
janjan	-.0000157	.0004008	-0.04	0.969	-.0008012	.0007699
aprapr	-.0001858	.0003001	-0.62	0.536	-.000774	.0004025
julyjuly	-.0009433	.0003619	-2.61	0.009	-.0016526	-.0002339
octoct	-.0003499	.000574	-0.61	0.542	-.0014749	.000775
beef	2.52e-07	1.63e-07	1.55	0.122	-6.71e-08	5.71e-07
pigs	1.72e-06	3.30e-07	5.21	0.000	1.07e-06	2.37e-06
dbsz	-.5231832	.0664782	-7.87	0.000	-.6534782	-.3928882
brsz	-.9374611	.0795301	-11.79	0.000	-1.093337	-.7815849
oatscwb	-.2808585	.0785415	-3.58	0.000	-.4347971	-.1269199
crowsnest	-.0459959	.1454953	-0.32	0.752	-.3311614	.2391697
pcp	-.3599233	.1045156	-3.44	0.001	-.5647701	-.1550764
pw	.0050879	.0038131	1.33	0.182	-.0023856	.0125614
pc	.0010608	.0013838	0.77	0.443	-.0016514	.0037731
pp	-.0003385	.0012098	-0.28	0.780	-.0027097	.0020327
ps	-.0012213	.0010939	-1.12	0.264	-.0033653	.0009228
pf	-.0086147	.0066297	-1.30	0.194	-.0216088	.0043793
th	.0175679	.0044735	3.93	0.000	.0087999	.0263358
_cons	.4963068	2.365161	0.21	0.834	-4.139324	5.131937

eta_tamehay						
jant	.0273445	.0222019	1.23	0.218	-.0161704	.0708593
aprt	.0097906	.0235852	0.42	0.678	-.0364356	.0560167
julyt	-.5752647	.2546543	-2.26	0.024	-1.074378	-.0761515
octt	.0384235	.0162976	2.36	0.018	.0064809	.0703662
janp	.0056703	.0091837	0.62	0.537	-.0123294	.02367
aprp	.0013994	.002874	0.49	0.626	-.0042335	.0070322
julyp	.0044847	.0071948	0.62	0.533	-.0096169	.0185863
oct	.0083508	.0057919	1.44	0.149	-.0030011	.0197027
jant2	.0006542	.0006048	1.08	0.279	-.0005312	.0018396
aprt2	.0002643	.0014582	0.18	0.856	-.0025938	.0031225
julyt2	.0173591	.0064731	2.68	0.007	.0046721	.030046
octt2	-.0006861	.0005479	-1.25	0.211	-.0017601	.0003878
janp2	-.0000105	.0000998	-0.11	0.916	-.0002061	.0001851
aprp2	-9.18e-06	.0000289	-0.32	0.751	-.0000659	.0000475
julyp2	1.09e-06	.000011	0.10	0.922	-.0000206	.0000227
octp2	-.0000725	.0000526	-1.38	0.169	-.0001756	.0000307
janjan	.000153	.0004387	0.35	0.727	-.0007067	.0010128
aprapr	-.0004769	.000314	-1.52	0.129	-.0010924	.0001386
julyjuly	-.000345	.0003746	-0.92	0.357	-.0010791	.0003891
octoct	-.0002527	.0005197	-0.49	0.627	-.0012714	.0007659
beef	1.03e-06	1.61e-07	6.42	0.000	7.17e-07	1.35e-06
pigs	3.91e-07	2.86e-07	1.37	0.172	-1.70e-07	9.52e-07
dbsz	-.5957785	.0632805	-9.41	0.000	-.7198061	-.471751
brsz	-.6711657	.0746748	-8.99	0.000	-.8175257	-.5248057
oatscwb	-.8304232	.08534	-9.73	0.000	-.9976864	-.6631599
crowsnest	-.1467431	.1602329	-0.92	0.360	-.4607937	.1673076
pcp	-.607675	.1050215	-5.79	0.000	-.8135133	-.4018367
pw	.008939	.0044904	1.99	0.047	.0001379	.0177401
pc	-.0050998	.0017288	-2.95	0.003	-.0084882	-.0017113
pp	.0042328	.0012493	3.39	0.001	.0017842	.0066814
ps	-.0012888	.0012624	-1.02	0.307	-.0037631	.0011854
pf	.0004735	.0078768	0.06	0.952	-.0149648	.0159118
th	.0173665	.005033	3.45	0.001	.0075021	.0272309
_cons	1.427236	2.527119	0.56	0.572	-3.525825	6.380298
eta_summerfallow						
jant	.0009511	.0157932	0.06	0.952	-.030003	.0319051
aprt	.0302224	.0204211	1.48	0.139	-.0098022	.070247
julyt	.391165	.2175937	1.80	0.072	-.0353109	.8176408
octt	.0213891	.0125869	1.70	0.089	-.0032808	.0460589
janp	-.0021783	.0080525	-0.27	0.787	-.0179609	.0136043
aprp	-.0002405	.0029017	-0.08	0.934	-.0059277	.0054467
julyp	.007103	.0058398	1.22	0.224	-.0043427	.0185487
oct	.0001556	.0038622	0.04	0.968	-.0074141	.0077254
jant2	.0000429	.0003939	0.11	0.913	-.0007291	.0008148
aprt2	-.0019562	.0014182	-1.38	0.168	-.0047358	.0008233
julyt2	-.0093491	.0054365	-1.72	0.085	-.0200044	.0013062
octt2	.0000825	.0006396	0.13	0.897	-.001171	.0013361
janp2	.0001451	.0000966	1.50	0.133	-.0000442	.0003344
aprp2	-4.48e-06	.0000349	-0.13	0.898	-.0000729	.0000639
julyp2	1.67e-06	7.06e-06	0.24	0.814	-.0000122	.0000155
octp2	-.0000185	.0000352	-0.53	0.599	-.0000874	.0000504
janjan	-.0000386	.0004228	-0.09	0.927	-.0008673	.0007901
aprapr	-.0001168	.0003295	-0.35	0.723	-.0007626	.000529
julyjuly	-.000427	.0003057	-1.40	0.162	-.0010262	.0001722
octoct	.0001265	.000423	0.30	0.765	-.0007025	.0009556
beef	-5.94e-07	1.40e-07	-4.25	0.000	-8.68e-07	-3.20e-07
pigs	-5.60e-07	2.27e-07	-2.47	0.013	-1.00e-06	-1.16e-07
dbsz	-.1595775	.0753449	-2.12	0.034	-.3072509	-.0119041
brsz	.2257278	.0832161	2.71	0.007	.0626272	.3888285
oatscwb	.1346984	.0690715	1.95	0.051	-.0006793	.2700761
crowsnest	.3061887	.1018217	3.01	0.003	.1066219	.5057555
pcp	-.0160657	.0647626	-0.25	0.804	-.1429981	.1108667
pw	-.0052918	.00334	-1.58	0.113	-.0118381	.0012546
pc	.0020859	.0012725	1.64	0.101	-.0004081	.0045799
pp	.0017531	.001097	1.60	0.110	-.000397	.0039033
ps	.0004243	.0011796	0.36	0.719	-.0018877	.0027363
pf	.0015678	.0050612	0.31	0.757	-.0083519	.0114874
th	-.0071501	.0034217	-2.09	0.037	-.0138565	-.0004437
_cons	-4.451266	2.114813	-2.10	0.035	-8.596223	-.3063093

C.1.4 FMLOGIT Marginal Effects

Marginal Effects	MFX at x coef.	se
wheat		
jant	7.2e-04	.0032
aprt	.0035	.0039
julyt	-.018	.0384
octt	-.0045	.0024
janp	-2.3e-04	.0015
aprp	8.1e-05	5.0e-04
julyp	-.0019	.0011
oct	-7.5e-04	8.0e-04
jant2	-4.1e-06	9.3e-05
aprt2	-2.2e-04	2.6e-04
julyt2	2.6e-04	9.7e-04
octt2	7.5e-05	9.6e-05
janp2	-8.3e-06	1.6e-05
aprp2	-1.1e-06	6.4e-06
julyp2	6.5e-07	1.6e-06
octp2	4.1e-06	7.0e-06
janjan	-2.2e-06	6.8e-05
aprapr	3.5e-05	5.5e-05
julyjuly	1.1e-04	5.9e-05
octoct	6.4e-05	8.1e-05
beef	4.0e-08	2.9e-08
pigs	-1.3e-07	4.6e-08
pw	1.1e-04	6.5e-04
pc	-7.9e-05	2.4e-04
pp	-6.4e-04	2.2e-04
ps	3.8e-04	1.9e-04
pf	-3.8e-04	.0011
th	-.0026	7.6e-04
canola		
jant	-.0027	.0018
aprt	-.0055	.0019
julyt	.0189	.0258
octt	.0026	.0011
janp	-3.4e-04	.0011
aprp	-1.3e-04	2.0e-04
julyp	5.4e-04	7.6e-04
oct	5.8e-04	4.1e-04
jant2	-8.0e-05	5.2e-05
aprt2	4.1e-04	1.2e-04
julyt2	-5.9e-04	6.9e-04
octt2	4.2e-05	5.3e-05
janp2	-1.5e-06	9.3e-06
aprp2	2.5e-06	1.7e-06
julyp2	-1.4e-06	9.6e-07
octp2	-9.4e-08	3.6e-06
janjan	-1.1e-06	4.1e-05
aprapr	4.2e-06	2.1e-05
julyjuly	-2.7e-05	4.1e-05
octoct	-1.1e-04	3.8e-05
beef	1.7e-08	1.4e-08
pigs	1.3e-07	2.1e-08
pw	-5.6e-04	3.5e-04
pc	1.3e-04	1.1e-04
pp	3.4e-04	1.1e-04
ps	-4.5e-04	1.1e-04
pf	.0014	6.1e-04
th	.0016	5.1e-04

pulses

jant	9.0e-04	6.6e-04
aprt	-.0021	8.7e-04
julyt	-.0097	.0084
octt	1.3e-04	5.7e-04
janp	-4.0e-04	3.3e-04
aprp	-2.0e-04	1.1e-04
julyp	-2.4e-04	3.8e-04
oct	7.6e-05	1.9e-04
jant2	3.0e-05	2.4e-05
aprt2	9.4e-05	5.3e-05
julyt2	2.3e-04	2.1e-04
octt2	-8.1e-06	2.6e-05
janp2	-3.2e-07	3.2e-06
aprp2	1.6e-06	8.6e-07
julyp2	4.8e-07	5.1e-07
octp2	-1.2e-06	1.7e-06
janjan	-1.7e-05	1.7e-05
aprapr	-6.2e-07	8.3e-06
julyjuly	4.7e-06	1.8e-05
octoct	-1.7e-05	1.7e-05
beef	1.5e-08	5.7e-09
pigs	-7.1e-09	9.3e-09
pw	3.4e-04	1.7e-04
pc	-1.3e-04	5.0e-05
pp	3.0e-04	4.9e-05
pf	-1.6e-04	3.0e-04
th	.0015	1.9e-04

feed

jant	-.0012	.0019
aprt	-.0063	.0023
julyt	-.0462	.0251
octt	-.0022	.0018
janp	5.7e-04	8.8e-04
aprp	-2.8e-05	2.7e-04
julyp	.0017	7.1e-04
oct	-2.6e-04	5.0e-04
jant2	2.2e-06	5.6e-05
aprt2	4.4e-04	2.1e-04
julyt2	.0014	6.4e-04
octt2	-1.1e-04	7.7e-05
janp2	-1.7e-05	1.2e-05
aprp2	3.0e-06	2.8e-06
julyp2	-6.1e-07	1.0e-06
octp2	7.5e-06	4.9e-06
janjan	-2.9e-06	4.1e-05
aprapr	-1.3e-05	3.0e-05

specialty

jant	-4.2e-04	.0011
aprt	-.001	.0012
julyt	.0098	.0203
octt	-5.3e-04	.0012
janp	7.4e-04	6.5e-04
aprp	1.7e-04	1.7e-04
julyp	-7.1e-04	5.2e-04
oct	3.4e-04	3.1e-04
jant2	-2.5e-06	3.6e-05
aprt2	-4.8e-05	9.2e-05
julyt2	-3.3e-04	5.2e-04
octt2	-3.1e-05	4.3e-05
janp2	-2.7e-06	4.6e-06
aprp2	-3.3e-06	1.7e-06
julyp2	-1.4e-07	6.1e-07
octp2	-3.8e-06	2.8e-06
janjan	2.4e-05	3.2e-05
aprapr	9.3e-06	2.4e-05
julyjuly	3.7e-05	2.6e-05
octoct	1.9e-05	3.2e-05
beef	-7.2e-08	9.0e-09
pigs	3.6e-08	1.5e-08
pw	1.0e-05	2.4e-04
pc	-1.5e-04	9.3e-05
pp	2.5e-05	6.1e-05
ps	-2.6e-05	6.5e-05
pf	2.6e-04	3.9e-04
th	7.5e-04	2.6e-04

tamehay

jant	.0021	.0012
aprt	.0013	.0013
julyt	-.044	.0146
octt	.0019	9.6e-04
janp	3.6e-04	5.2e-04
aprp	1.1e-04	1.6e-04
julyp	-1.6e-05	4.2e-04
oct	4.6e-04	3.4e-04
jant2	4.6e-05	3.3e-05
aprt2	-2.1e-05	8.1e-05
julyt2	.0013	3.7e-04
octt2	-3.5e-05	3.3e-05
janp2	-2.2e-06	5.8e-06
aprp2	-8.4e-07	1.4e-06
julyp2	1.9e-07	6.3e-07
octp2	-4.4e-06	3.1e-06
janjan	1.0e-05	2.5e-05
aprapr	-2.8e-05	2.0e-05

julyjuly	-8.8e-05	3.7e-05
octoct	-2.6e-05	5.8e-05
beef	4.7e-08	1.5e-08
pigs	1.9e-07	3.3e-08
pw	7.2e-04	3.7e-04
pc	1.2e-04	1.4e-04
pp	-2.6e-04	1.1e-04
ps	-3.5e-05	1.2e-04
pf	-.0013	6.3e-04
th	.0015	4.3e-04

julyjuly	-4.2e-06	2.2e-05
octoct	-6.6e-06	3.1e-05
beef	8.0e-08	8.2e-09
pigs	5.1e-09	1.7e-08
pw	6.5e-04	2.5e-04
pc	-3.8e-04	9.8e-05
pp	1.9e-04	6.6e-05
ps	-2.4e-05	7.3e-05
pf	-3.3e-05	4.4e-04
th	7.7e-04	2.8e-04

summerfallow		
jant	7.1e-04	.0032
aprt	.01	.0039
julyt	.089	.0447
octt	.0026	.0026
janp	-7.1e-04	.0017
aprp	-9.9e-06	5.4e-04
julyp	6.1e-04	.0012
oct	-4.4e-04	7.9e-04
jant2	8.4e-06	8.1e-05
aprt2	-6.5e-04	3.1e-04
julyt2	-.0022	.0011
octt2	6.9e-05	1.3e-04
janp2	3.2e-05	1.9e-05
aprp2	-1.8e-06	5.8e-06
julyp2	8.4e-07	1.5e-06
octp2	-2.1e-06	7.6e-06
janjan	-1.1e-05	8.9e-05
aprapr	-7.4e-06	6.1e-05
julyjuly	-3.6e-05	6.4e-05
octoct	7.3e-05	8.6e-05
beef	-1.3e-07	2.7e-08
pigs	-2.3e-07	5.0e-08
pw	-.0013	6.6e-04
pc	4.9e-04	2.4e-04
pp	4.0e-05	2.0e-04
ps	3.5e-04	2.4e-04
pf	1.6e-04	.001
th	-.0035	6.9e-04

C.2 Robustness Testing

Between the two models estimated the second model including soil zones representing land characteristics, policy variables and price variables improved the overall fit of the model. The Wald Chi^2 statistic improved from 1,977.69 to 15,299.13 by including these variables.

Further to this a Likelihood Ratio test was conducted to compare the two estimated models. This was done in STATA as well as by hand and both results were as follows.

The critical Chi^2 value at 1% significance and 12 degrees of freedom is 27.7. The estimated Chi^2 statistic was calculated as follows:

$$LR = 2(\ln m2 - \ln m1) \quad (1.1)$$

Where lnm2 and lmn1 are the estimated log pseudoliklihood for models 2 and 1, respectively.

LR = 49.9725

Rejection Criteria $\chi^2_{cr} > \hat{\chi}^2$ Reject H_o – Addition of variables jointly improves the model

27.7<49.9725 Therefore, DNR the H_o, the model is in fact improved with the addition of the variables.